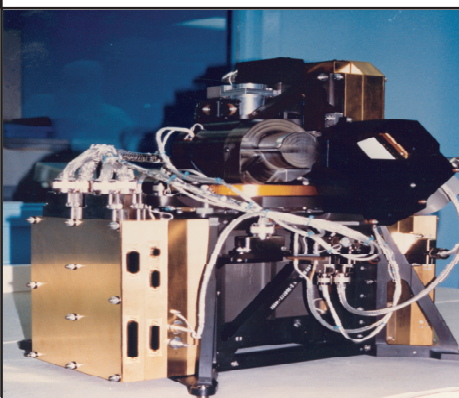
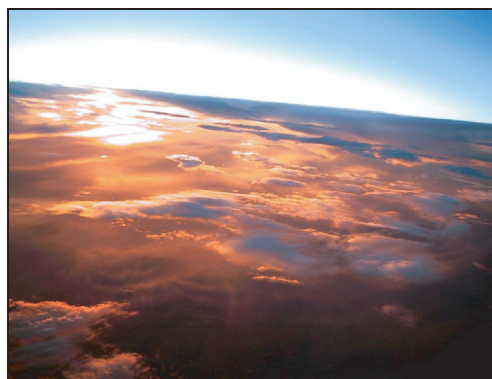


Laboratory for Atmospheres Instrument Systems Report



The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

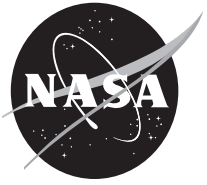
For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at <http://www.sti.nasa.gov/STI-homepage.html>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621-0134
- Telephone the NASA Access Help Desk at (301) 621-0390
- Write to:
NASA Access Help Desk
NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320

Cover Caption: Pictures in order of from top to bottom:

1. Red clouds in the Earth's upper atmosphere.
2. Earth Probe TOMS instrument.
3. The Scanning Raman Lidar (SRL) deployed at Andros Island, Bahamas during CAMEX-3.

More information can be found at the Laboratory Web site: <http://atmospheres.gsfc.nasa.gov>.



Laboratory for Atmospheres Instrument Systems Report

National Aeronautics and
Space Administration

**Goddard Space Flight Center
Greenbelt, Maryland 20771**

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A10



National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

Foreword

Studies of the atmospheres of our solar system's planets—including our own—require a comprehensive set of observations, relying on instruments on spacecraft, aircraft, balloons, and on the surface. These instrument systems perform one or both of the following: 1) provide information leading to a basic understanding of the relationship between atmospheric systems and processes, and 2) serve as calibration references for satellite instrument validation. Laboratory personnel define requirements, conceive concepts, and develop instrument systems for spaceflight missions, and for balloon, aircraft, and ground-based observations. Balloon and airborne platforms facilitate regional measurements of precipitation, cloud systems, and ozone from high-altitude vantage points, but still within the atmosphere. Such platforms serve as stepping-stones in the development of space instruments. Satellites provide nearly global coverage of the Earth with spatial resolutions and repetition rates that vary from system to system. The products of atmospheric remote sensing are invaluable for research associated with water vapor, ozone, trace gases, aerosol particles, clouds, precipitation, and the radiative and dynamic processes that affect the climate of the Earth. These parameters also provide the basic information needed to develop models of global atmospheric processes and weather and climate prediction. Laboratory scientists also participate in the design of data processing algorithms, calibration techniques, and the data processing systems.

The instrument sections of this report are organized by measurement technique, e.g., active, passive, and *in situ*. Active systems include lidar and microwave radar, passive systems include optical and microwave systems, and *in situ* systems consist of mass spectrometers for planetary atmosphere measurements. A number of instruments are in various stages of development or modification and are described in the section titled: Research and Development. This section also includes the Brewer Spectrophotometer, which will undergo modification for improved capability, but is used for calibration and scientific measurements. This report will be updated as instrument systems evolve and change.

While this report was being prepared, the Goddard science organizations underwent a transformation that combined the Space and Earth Sciences Directorates. The instrument activities described herein, however, remain current. The merging of Space and Earth Sciences Directorates is expected to bring new opportunities for sciences and exploration. A copy of this report can be found on the Laboratory for Atmospheres Web site—<http://atmospheres.gsfc.nasa.gov>.

We wish to thank all of the Laboratory members who contributed material on the various instrument systems, and especially the efforts of Laura Rumburg, Natalie Simms, and Caroline Maswanganye for their formatting, proofreading, editing, and printing support.

Sincerely,

A handwritten signature in black ink, appearing to read "William K.-M. Lau".

William K.-M. Lau, Chief

A handwritten signature in black ink, appearing to read "Charles E. Cote".

Charles E. Cote, Associate Chief

June 2005

Table of Contents

Diagram of Lidar and Passive Optical Instruments	v
Diagram of Lidar and Passive Optical Instruments	vii
Lidar Instrument Systems	1
AROTAL	2
AT Lidar	4
CPL	5
GLOW	6
HARLIE	8
KILT	10
MPL	12
RASL	14
SRL	16
STROZ LITE	18
THOR	20
Passive Optical Instrument Systems	21
COVIR	22
EPIC	24
SMART	26
SSBUV	28
TOMS	30
<i>In Situ</i> Instrument Systems	33
COMMIT	34
GCMS	36
INMS	38
Microwave Instrument Systems	41
CRS	42
EDOP	44
LRR-X	46
Research and Development Instrument Systems	47
AirGLOW	48
Brewer	50
GeoSpec	52
<i>In Situ</i>	53
SVIP	54
UAV CPL	55
Acronyms	57

Diagram of Lidar and Passive Optical Instruments

On the opposite page, spectral wavelength bands are pointed out for lidar and passive optical instrument systems. Space-, airborne-, and ground surface systems are identified along with the primary products produced from the various measurements.

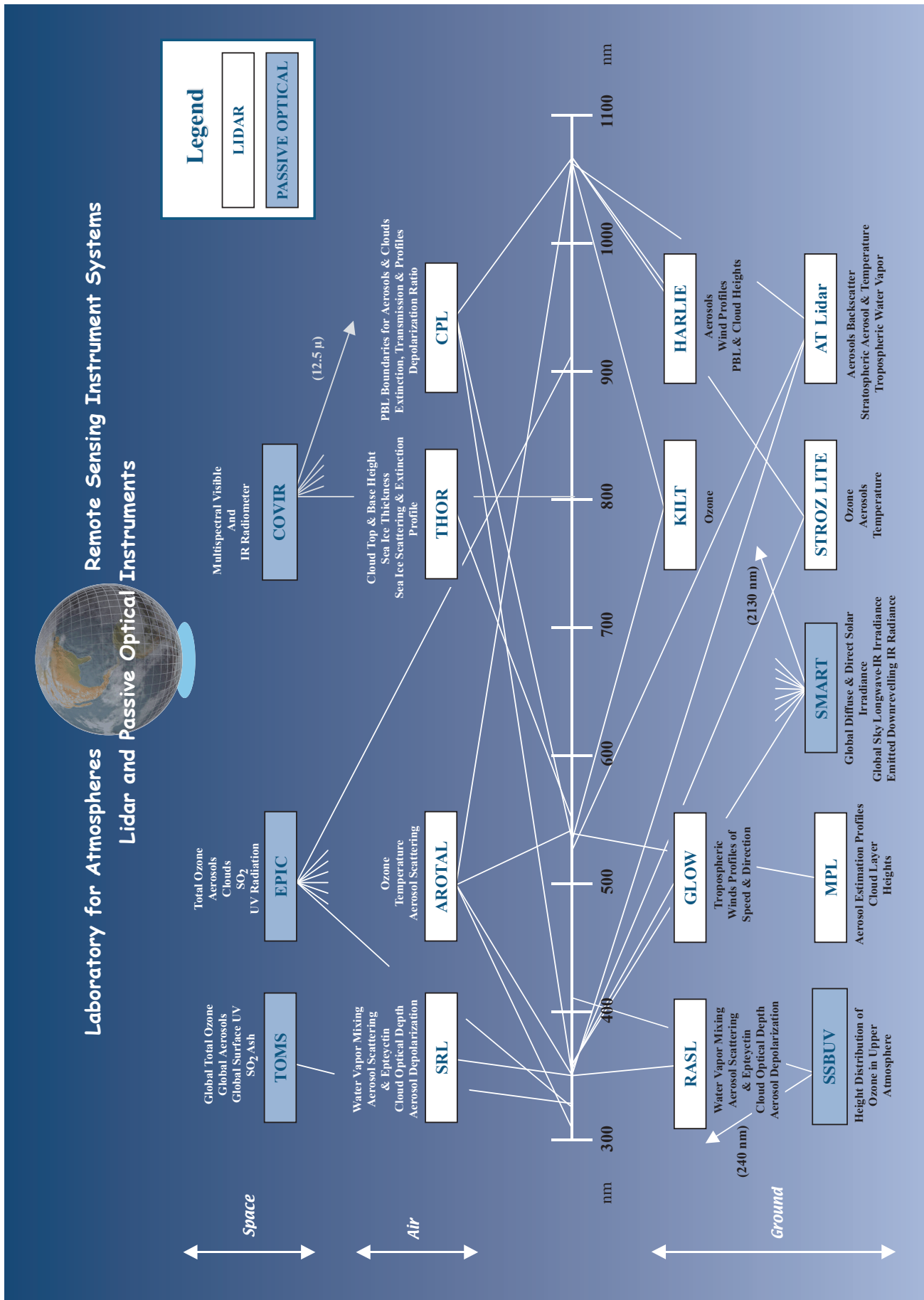
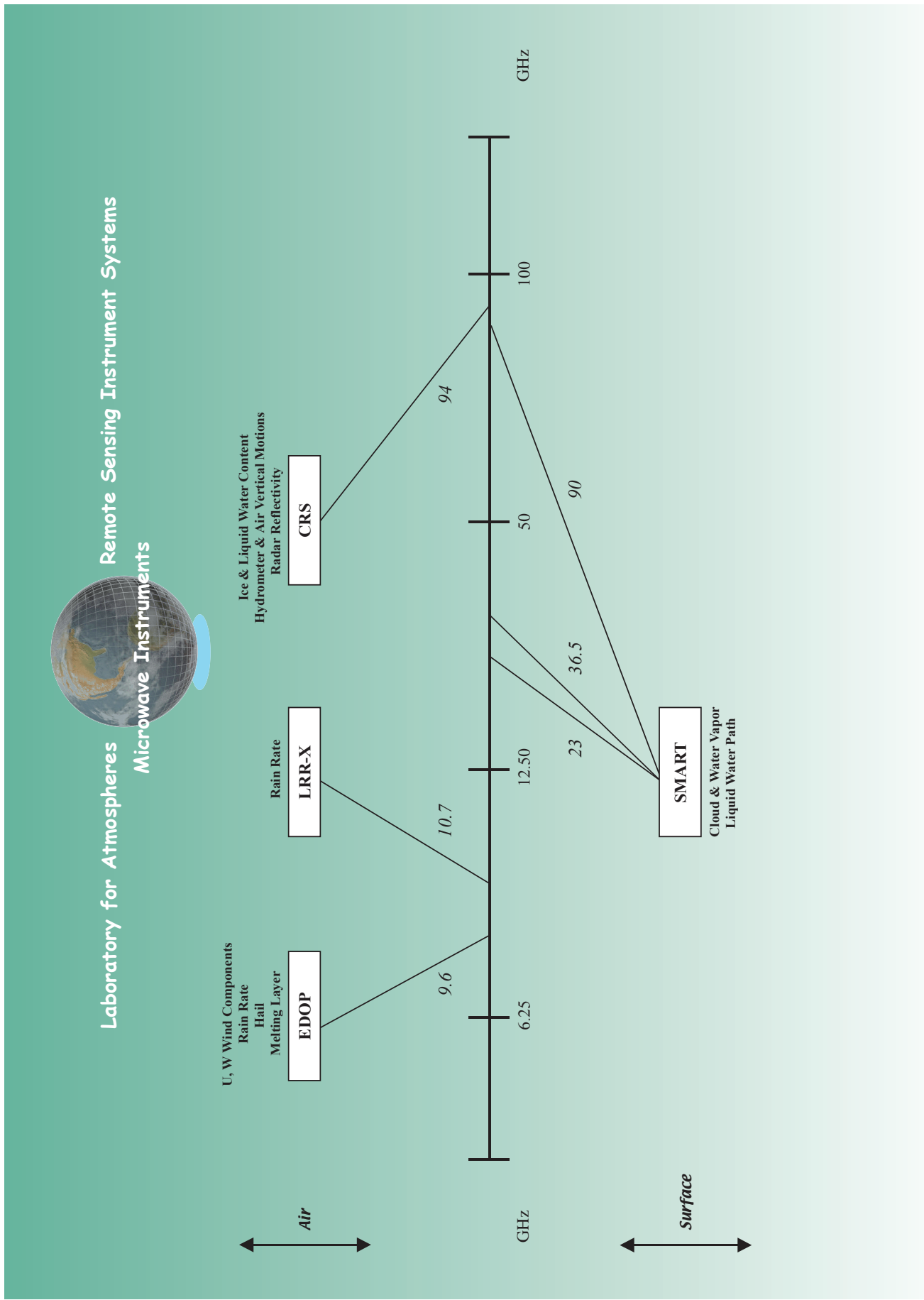


Diagram of Lidar and Passive Optical Instruments

On the opposite page, spectral wavelength bands are pointed out for active and passive microwave instrument systems. Airborne- and ground surface systems are identified along with the primary products produced from the various measurements.



LIDAR INSTRUMENT SYSTEMS



AROTAL

Airborne Raman Ozone, Temperature, and Aerosol Lidar



AROTAL in a DC-8; up-looking telescope (black cylinder) and one laser showing.

Key ARODAL Facts

- Heritage: Originally designed for temperature and methane; modified to include temperature, ozone, and aerosol.
- A visible infrared/ultraviolet lidar for polar atmospheric measurements above 12 km.
- Participated in the 1999/2000 SOLVE campaign and the 2003 SAGE III validation campaign in Kiruna, Sweden.
- Nominal field configuration: Designed for deployment on the NASA DC-8 aircraft with the telescope looking up through a 16-in diameter quartz window.
- ARODAL URL: <http://hyperion.gsfc.nasa.gov>

Description

Ozone loss in the polar stratosphere is directly caused by catalytic chlorine and bromine reactions. The high levels of reactive chlorine occur because of reactions of reservoir chlorine species on the surfaces of polar stratospheric clouds (PSCs). Temperature plays a key role in the formation and lifetime of PSCs. In part because of temperature's pivotal role, ARODAL provides high-resolution profiles of the arctic temperature fields. Lidar retrievals from the DC-8 provide high-precision temperature profiles, along with measurements of ozone, aerosols, clouds, and water vapor throughout the region of interest. These measurements were designed to help understand the conditions under which PSCs form and persist by identifying regions in the lower Arctic stratosphere where temperatures were low enough for PSCs to persist (195 K or lower).

AROTAL is made up of three major components: the transmitter, the receiver, and the data acquisition system. The transmitter comprises two different lasers: an XeCl excimer

laser, transmitting 308 nm; and a Nd-YAG laser, transmitting at 1064, 532, and 355 nm. The primary receiver is a 16-in Newtonian telescope. The visible and infrared radiation is split from the ultraviolet wavelengths; the 532 nm radiation is polarized 90° to the transmitted 532 nm radiation and is also collected. Ultraviolet returns are separated into four wavelengths: the two transmitted wavelengths at 308 and 355 nm, as well as the Raman scattered return from atmospheric N₂ at 332 and 387 nm.

AROTAL Data Products

Vertical profiles of:

- O₃ from 14–30 km
- Temperature, 13–60 km
- Aerosol scattering
- Aerosol depolarization at 532 nm

AROTAL Parameters

- Laser wavelengths: 308, 355, 532, and 1064 nm
- Laser pulse energy: 200 mJ
- Pulse Rate: 50 Hz at 1064, 532, and 355 nm; 200 Hz at 308 nm
- Field of view: typically 2 mrad (variable)
- Optical channels: 308, 332, 355, 387, 532, and 1064 nm
- Horizontal resolution: 4–48 km
- Vertical resolution: 0.5–1.5 km

Principal Investigator

Thomas J. McGee
NASA Goddard Space Flight Center
Thomas.J.McGee@nasa.gov

AROTAL Team Members

John Burris, (Co-PI)
NASA Goddard Space Flight Center

Robert Farmer
NASA Goddard Space Flight Center

William Heaps
NASA Goddard Space Flight Center

Walter Hoegy
NASA Goddard Space Flight Center

Chris Hostetler
NASA Langley Research Center

Leslie Lait
Science Systems and Applications, Inc.

Donald Silbert
NASA Goddard Space Flight Center

Chip Trepte
NASA Langley Research Center

Lawrence Twigg
Science Systems and Applications, Inc.

Future Campaigns
AURA validation, 2005

Co-Investigators

Paul Newman
NASA Goddard Space Flight Center

Mark Schoeberl
NASA Goddard Space Flight Center

Stuart McDermid
NASA Jet Propulsion Laboratory

Science Questions for Future Campaigns

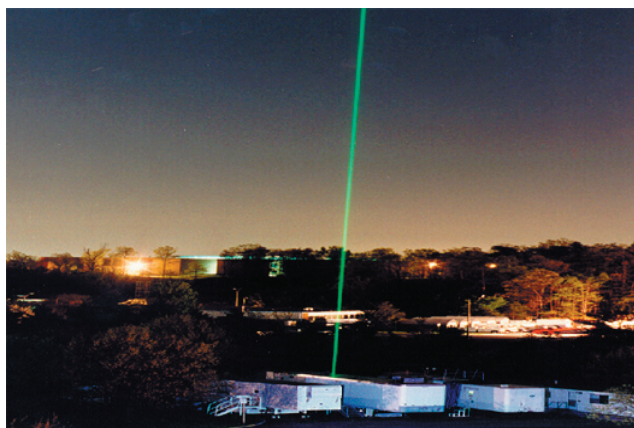
1. What is the validity of the ozone measuring instruments on board the Aura satellite?
2. What is the effect of the ozone variability within the Aura measurement footprint?

References

- Burris, J., T. McGee, W. Hoegy, L. Lait, L. Twigg, G. Sumnicht, W. Heaps, C. Hostetler, T. Bui, R. Neuber, and I.S. McDermid, 2002: Validation of temperature measurements from the Airborne Raman Ozone Temperature and Aerosol Lidar (AROTAL) during SOLVE. *J. Geophys. Res.*, **107**, D20, 8286–8296.
- , —, —, P. Newman, L. Lait, L. Twigg, G. Sumnicht, W. Heaps, C. Hostetler, R. Neuber, and K. Kunzi, 2002: Lidar temperature measurements during the SOLVE campaign and the absence of PSCs from regions of very cold air. *J. Geophys. Res.*, **107**, D20, 8297–8306.

AT Lidar

Aerosol and Temperature Lidar



AT Lidar operating at GSFC; 532 nm beam is clearly visible.

Key AT Lidar Facts

- Heritage: Originally designed for stratospheric parameters; modified to include the troposphere.
- The AT Lidar is an elastic and Raman backscatter lidar designed for aerosol and temperature profiling in the stratosphere and above; and for tropospheric water vapor and temperature, cirrus cloud parameters, and temperature within cirrus clouds.
- Nominal field configuration: The system is mobile and is housed in a large, environmentally controlled trailer.

Description

This Lidar system has high sensitivity aerosol and temperature capabilities using two separate Nd-YAG lasers to transmit three different wavelengths: 1064, 532, and 355 nm. Returns from the spectrally narrow transmitted 1064 and 532 nm beams are used to measure aerosol backscatter into the stratosphere. The depolarization ratio of the 532 nm radiation is measured to determine the physical state of the particles. The transmitted 532 nm beam is spectrally narrow and rotational. Raman lines scattered from nitrogen can be spectrally resolved. These lines are temperature sensitive, so temperature within cirrus clouds can be retrieved. Raman scattering of the transmitted 532 nm radiation from nitrogen (607 nm radiation) is also collected. Raman scattered returns from nitrogen (at 387 nm) and water vapor (at 407 nm) are also collected from the transmitted 355 nm beam. The ratio of the elastically scattered 355 or 532 nm radiation to the corresponding Raman scattered return at 387 or 607 nm, allows for the direct measure of the aerosol backscatter ratio. The ratio of the 407 nm return to the 387 nm return yields a relative water vapor profile. This can be calibrated

to yield an absolute measurement of the tropospheric water vapor profile.

AT Lidar Data Products

- Aerosol backscatter at 1064, 532, and 355 nm
- Aerosol depolarization at 532 nm
- Aerosol backscatter and extinction at 532 and 355 nm
- Stratospheric aerosol and temperature
- Tropospheric water vapor
- Tropospheric temperature (includes within clouds)

AT Lidar Parameters

- Laser wavelengths: 1064, 532, 355 nm at 50 Hz
- Optical returns: 1064, 532, 607, 355, 387, 407 nm
- Vertical resolution (raw signal): 15 m
- Telescope: 36-in Newtonian

Principal Investigator

Thomas J. McGee
NASA Goddard Space Flight Center
Thomas.J.McGee@nasa.gov

AT Lidar Team Members

Paul Newman
NASA Goddard Space Flight Center

Donald Silbert
NASA Goddard Space Flight Center

Grant Sumnicht
Science Systems and Applications, Inc.

Laurence Twigg
Science Systems and Applications, Inc.

Co-Investigators

Jens Reichardt
German Weather Service

Science Question for Future Campaigns

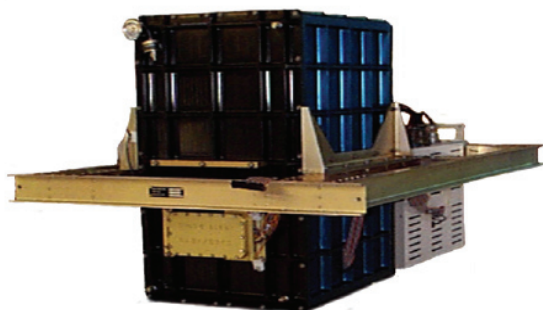
1. What determines the formation of cirrus cloud particles as a function of temperature within the cloud?

References

Beyerle, G., M.R. Gross, D.A. Haner, N.T. Kjome, I.S. McDermid, T.J. McGee, J.M. Rosen, H.J. Schaefer, and O. Schrems, 2001: STRAIT '97: An aerosol lidar and backscatter sonde intercomparison campaign at Table Mountain Observatory during February–March 1997, *J. Atmos. Sci.*, **58**, 1275–1287.

CPL

Cloud Physics Lidar



The ER-2 CPL system in flight configuration.

Key CPL Facts

- Heritage: Cloud Lidar System (CLS)
- ER-2 airborne lidar for cloud and aerosol profiling. Provides cloud/layer boundary, depolarization ratio, optical depth, and extinction ratios.
- Participated in the 2002 CRYSTAL-FACE field campaign and a MODIS validation campaign.
- Nominal Flight Characteristics: 65,000 ft (20 km), above 94% of Earth's atmosphere. Nadir viewing, 9 h duration time with 5 Gb storage.
- CPL URL: <http://cpl.gsfc.nasa.gov>

Description

The effect of clouds and aerosols on regional and global climate is of great scientific importance. Long-standing elements of the NASA climate and radiation science program are field studies incorporating airborne remote sensing and in situ measurements of clouds and aerosol. The CPL system is designed specifically for studying clouds and aerosols using the ER-2 High Altitude Aircraft. Because the ER-2 typically flies at 65,000 ft (20 km), its instruments are above 94% of the Earth's atmosphere, thereby allowing ER-2 instruments to function as spaceborne instrument simulators. The CPL provides a unique tool for atmospheric profiling and is sufficiently small and low cost to include in multiple instrument missions. Active lidar profiling is especially valuable because the cloud height structure is measured unambiguously, up to the limit of signal attenuation.

CPL Data Products

- Planetary Boundary Layer (PBL) Boundaries for Aerosols and Clouds
- Layer Optical Depth
- Layer Extinction-to-Backscatter Ratio(s) Used
- Layer Extinction Profile
- Layer Transmission Profile
- Images of Extinction and Optical Depth
- Depolarization Ratio

CPL Parameters

- Vertical Resolution: 30 m
- Horizontal Resolution: 200 m
- Wavelengths: 1064, 532, and 355 nm
- Laser Repetition Rate: 5000 Hz
- Laser Pulse Energy: 50 mJ at 1064 nm; 25 mJ at 532 nm; 50 mJ at 355 nm
- Total Power: 60 W
- Weight: 50 kg
- FOV: 100 μ rad

Principal Investigator

Matthew J. McGill
NASA Goddard Space Flight Center
Matthew.J.McGill@nasa.gov

Co-Investigators

William Hart
Science Systems and Applications, Inc.

Dennis Hlavka
Science Systems and Applications, Inc.

Scientific Questions for Future Campaigns

1. What are the particle sizes within clouds?
2. What is the effect of multiple scattered signals on estimates of extinction-to-backscatter and optical depth?

Future Campaigns

- AURA validation campaign, 2004–2005
- CALIPSO and CloudSat validation, 2005
- Yearly campaigns supporting various Earth Science missions or experiments.

References

- McGill, M.J., D.L. Hlavka, W.D. Hart, J.D. Spinhirne, V.S. Scott, and B. Schmid, 2002: The cloud physics lidar: Instrument description and initial measurement results. *Appl. Opt.*, **41**, 3725–3734.
- , L. Li, W.D. Hart, G.M. Heymsfield, D.L. Hlavka, P.E. Racette, L. Tian, M.A. Vaughan, and D.M. Winker, 2004: Combined lidar-radar remote sensing: Initial results from CRYSTAL-FACE. *J. Geophys. Res.*, **109**, D07203, doi: 10.1029/2003JD004030.
- , D.L. Hlavka, W.D. Hart, E.J. Welton, and J.R. Campbell, 2003: Airborne lidar measurements of aerosol optical properties during SAFARI-2000. *J. Geophys. Res.*, **108**, doi: 10.1029/2002JD002370.

GLOW

Goddard Lidar Observatory for Winds



The GLOW mobile Doppler lidar measures wind profiles from surface into the stratosphere. The 2-axis scanner (on roof) allows full-sky scanning of the lidar.

Key GLOW Facts

- Heritage: Double Edge Wind Lidar, and Zephyr New Millennium Program Formulation Study (Shuttle).
- It is a mobile system for determining vertical profiles of wind from the Doppler-shifted frequency of the laser signal scattered back towards the lidar. Profiles of wind speed and direction are produced by this system.
- GLOW participated in the 2002 International H₂O Project (IHOP-2002) <<http://www.joss.ucar.edu/ihop/>>.
- Nominal Field Configuration: Truck-based scanning Doppler lidar designed for day and night operation. Step stare scanning in azimuth (0–360°) with fixed elevation angle (0–90°).
- GLOW URL: <http://glow.gsfc.nasa.gov>

Description

Tropospheric winds are recognized as the single most important measurement for improved weather forecasting. Winds are also required for a variety of research applications requiring knowledge of the atmospheric dynamics for process and transport studies. GLOW is a mobile wind lidar system, which uses direct detection Doppler lidar techniques for measuring wind profiles up to 35 km. The GLOW mobile lidar system has a twofold purpose:

- 1) To provide wind profile measurements from the surface into the stratosphere for use in scientific measurement programs, and
- 2) As a testbed for validating the performance of new technologies and measurement techniques proposed for use in future spaceborne applications.

Future plans include spaceborne observation of global winds, as well as ground- and airborne measurements of winds for investigation of mesoscale dynamics and atmospheric processes.

GLOW Data Products

- Range resolved scans (i.e., plan position indicator [PPI], and range-height indicator [RHI]) of radial wind speed
- Vertical profiles: u , v , w component winds and wind speed and direction
- Coverage: 0.1–30 km
- Minimum range resolution: 40 m
- Accuracy: 0.5–3 m s⁻¹

GLOW Parameters

- Laser wavelengths: 1064 nm, 355 nm
- Laser pulse energy: 50 mJ at 355 nm
- Pulse repetition rate: 50 Hz
- Telescope/scanner aperture: 45 cm
- FOV: 0.2 mrad

Principal Investigator

Bruce Gentry
NASA Goddard Space Flight Center
Bruce.M.Gentry@nasa.gov

GLOW Team Members

Huailin Chen
Science Systems and Applications, Inc.

Joseph Comer
Science Systems and Applications, Inc.

Steven Li
NASA Goddard Space Flight Center

Savyasachee Mathur
SigmaSpace Inc.

Gerry McIntire
Raytheon Technical Services Company

Science Questions for Future Campaigns

1. Can wind observations in and around a tropical cyclone improve the prediction of hurricane intensity and track?
2. Can wind profile observations through the tropopause improve understanding of tropospheric/stratospheric exchange?

References

- Demoz, B., D. Miller, K. Evans, D. Whiteman, P. Di Girolamo, G. Schwemmer, B. Gentry, D. Starr, and Z. Wang, 2003: Moisture, wind and boundary layer evolution during a dryline in IHOP-2002: May 22, 2002. *Int. Symp. Tropospheric Profiling*, Leipzig, Germany, September 2003, 387–389.
- Gentry, B., 2001: Advances in direct detection doppler lidar technology and techniques. *Proc. 2001 Int. Geosci. Remote Sens. Symp.*, Sydney, Australia, 9–14 July, 2001, 751–753.
- , H. Chen, and S.X. Li, 2000: Wind measurements with a 355 nm molecular Doppler lidar. *Opt. Lett.*, **25**, 1231–1233.
- , and —, 2002: Profiling tropospheric winds with the Goddard Lidar Observatory for Winds (GLOW). *Proc. 21st Int. Laser Radar Conf.*, Quebec City, Canada, 8–12 July 2002, 821–824.
- , and —, 2002: Performance validation and error analysis for a direct detection molecular Doppler lidar. Invited Paper, *SPIE Third Int. Asia-Pacific Environ. Remote Sens. Conf.*, Hangzhou, 23–27 October 2002, 287–294.
- , —, S.X. Li, S. Mathur, J. Dobler, and W. Hasselbrack, 2003: Tropospheric wind profiles obtained with the GLOW molecular Doppler lidar during the 2002 International H₂O Project. *Int. Symp. Tropospheric Profiling*, Leipzig, Germany, September 2003, 6–8.
- Korb, C.L., B. Gentry, and S.X. Li, 1997: Edge technique Doppler lidar wind measurements with high vertical resolution. *Appl. Opt.*, **36**, 5976–5983.
- , —, —, and C. Flesia, 1998: Theory of the double-edge technique for Doppler lidar wind measurement. *Appl. Opt.*, **37**, 3097–3104.

HARLIE

Holographic Airborne Instrument Experiment



Photo of HARLIE Transceiver and 40.6 cm Holographic Optical Element (HOE).

Key HARLIE Facts

- Heritage: Director's Discretionary Fund (DDF) 1989 and 1991
- A unique scanning and motion holographic telescope, to measure atmospheric profiles of aerosol, boundary layer and cloud top heights, cloud bottom heights, and wind profiles with high temporal resolution.
- Participated in several field campaigns including IHOP, ARMIP2000, and HARGLO.
- Nominal deployment characteristics:
 - Surface: Housed in an environmentally controlled mobile trailer.
 - Aircraft: Transceiver mounted on a frame a few centimeters from a viewing window provides a 200 μ rad FOV and sweeps out a 45° cone.
- HARLIE URL: <http://harlie.gsfc.nasa.gov/>

Description

HARLIE measures cloud and aerosol structure and dynamics via laser backscatter in three dimensions. Using a unique conical scanning holographic telescope and a diode-pumped solid-state infrared laser, this compact high-performance lidar fits into low- to medium-altitude aircraft, as well as in a portable ground-based environmental housing for relatively low cost field experiment deployments. HARLIE will also be used to test concepts for an airborne direct detection wind lidar, which could one day be used for space borne applications. It uses a 40 cm diameter by 1 cm thick HOE as the receiver collecting and focusing aperture. It has a 45° diffraction angle and a 1 m focus normal to its surface. It is continuously scanned up to 30 rpm, and can also operate in step-and-stare, or static, modes.

HARLIE Data Products

- Aerosol backscatter profiles: 20 m and 100 ms resolution

- Boundary layer and cloud heights: ± 20 m, 100 ms intervals
- Cloud fraction vs. altitude
- Wind profiles: ± 2 m s⁻¹, 200 m vertical, 15 min time resolution

HARLIE Parameters

- Laser wavelength: 1064 nm
- Laser power: 200 μ J
- Laser pulse rate: 5 kHz
- Scan modes: Continuous up to 30 rpm, point-and-stare, 8-position step-stare, sector and 3-D scanning

Principal Investigator

Geary K. Schwemmer
 NASA Goddard Space Flight Center
Geary.K.Schwemmer@nasa.gov

HARLIE Team Members/Co-Investigators

David Guerra
 Saint Anselm College, Manchester, New Hampshire

Sangwoo Lee
 Science Systems and Applications, Inc.

Gerry McIntire
 Raytheon Technical Services Company

David O. Miller
 Science Systems and Applications, Inc.

Thomas Wilkerson
 Utah State University

Science Questions for Future Campaigns

1. What are atmospheric profiles of backscattered aerosols during the daytime?
2. How do gravity waves interact with, and organize convection in, the Planetary Boundary Layer?
3. How important are convectively-driven gravity waves in transferring momentum and energy to the free troposphere?

Future Campaigns

A proposal was submitted for participation in the heat island experiment in the 2005–2006 timeframe.

References

- Berkoff, T.A., D.N. Whiteman, R.D. Rallison, G.K. Schwemmer, L. Ramos-Izquierido, and H. Plotkin, 2000: Remote detection of raman scattering by use of a holographic optical element as a dispersive telescope. *Opt. Lett.*, **25**, 1201–1203.

- Guerra, D., G. Schwemmer, A. Wooten, S. Chaudhuri, and T. Wilkerson, 1999: Prototype holographic atmospheric scanner for environmental remote sensing. *J. Geophys. Res.*, **104**, 22,287–22,292.
- Schwemmer, G., 1993: Conically scanned holographic LIDAR telescope. *NASA Tech Briefs*, **17**, 61–62.
- , T. Wilkerson, and D. Guerra, 1998: “Compact scanning lidar systems using holographic optics.” In: Optical Remote Sensing for Industry and Environmental Monitoring, U.N. Singh, H. Hu, and G. Wang, Eds., *Proc. SPIE*, **3504**, Beijing, China, 14–17 September 1998, 51–59.
- , —, J.A. Sanders, D.V. Guerra, D.O. Miller, and S.E. Moody, 2001: “Ground based operational testing of holographic scanning lidars.” In: *Advances in Laser Remote Sensing*, A. Dabas, C. Loth, and J. Pelon, Eds., Ecole Polytechnique, France, 69–72.

KILT

Kiritimati Island Lidar Trailer



KILT was deployed at the Jet Propulsion Laboratory's (JPL) Table Mountain Facility North of Los Angeles, California. The power generating solar panels and windmill are visible in this picture.

Key KILT Facts

- KILT is an autonomous, elastic backscatter/depolarization lidar instrument for the measurement of cloud parameters from a remote location. The instrument will generate a cirrus cloud climatology in the tropical Pacific, above Kiritimati (also known as “Christmas”) Island (2°N lat).
- Nominal field configuration: The system is mobile and uses solar panels and a windmill to generate the power necessary to operate the instrument. It is expected to operate in the field for 1–2 years.

Description

In the current environment of concern over global warming, climate change, and ozone depletion/recovery, measurements in the tropics, within $\pm 5^\circ$ of the equator are limited and/or sporadic. Routine observations in this region are, therefore, of great benefit to many programs including those dealing with atmospheric chemistry, dynamics and radiation, and validating satellite instruments. Kiritimati Island is located in the equatorial dry zone of the central Pacific where significant rainfall only occurs during the warm phase

of the Southern Oscillation. The thick, persistent cloud cover typical in the convectively-active western Pacific is absent in the region of Kiritimati Island thus providing the clear skies required for the atmospheric observations to be made by KILT. There is a clear need for long-term, high spatial resolution, depolarization lidar observations of cirrus cloud layers near the equator. KILT is an autonomous, eye-safe instrument. It transmits two laser wavelengths, 1064 and 532 nm, at a 2,500 Hz pulse repetition frequency, at a total energy of 200 μ J per pulse. The 532 nm return is separated into parallel and perpendicular polarizations, to measure the depolarization caused by scattering from irregular particles (ice, in cirrus clouds). Data will be transferred via satellite phone to a server at Table Mountain.

KILT Data Products

- Aerosol backscatter at 532 and 1064 nm
- Aerosol depolarization at 532 nm

KILT Parameters

- Laser wavelengths: 1064 and 532 nm at 2.5 kHz
- Optical returns: 1064, 532 nm (parallel and perpendicular)
- Vertical resolution (raw signal): 15 m
- Telescope: 12-in Cassegrain

Principal Investigators

Thomas J. McGee
NASA Goddard Space Flight Center
Thomas.J.McGee@nasa.gov

I. Stuart McDermid

Jet Propulsion Laboratory, Table Mountain Facility

Co-Investigators

Thierry LeBlanc
Jet Propulsion Laboratory

Donald Silbert
NASA Goddard Space Flight Center

Grant Sumnicht
Science Systems and Applications, Inc.

Laurence Twigg
Science Systems and Applications, Inc.

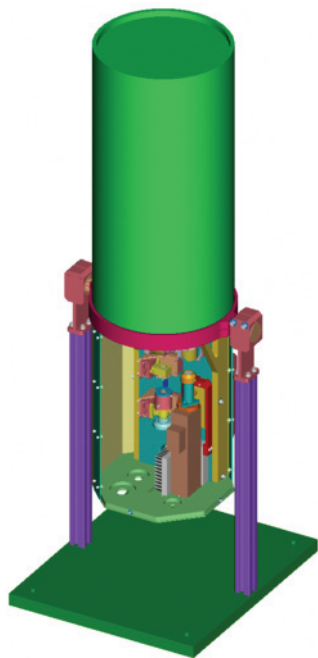
Science Questions for Future Campaigns

1. What is the cirrus cloud climatology above an equatorial Pacific site?
2. What is the frequency and extent of sub-visible cirrus clouds? Is Kiritimati Island suitable for a long-term NDSC facility?

This page was intentionally left blank.

MPL

Micro-Pulse Lidar



MPL digital image courtesy of Welch Mechanical Designs, LLC.

Key MPL Facts

- Heritage: GSFC DDF
- The instrument is a compact and eye-safe lidar capable of profiling the vertical structure of aerosols and clouds up to 20+ km. The design was engineered for deployments to remote field locations requiring continuous lidar observations.
- Nominal field configuration: Global ground-based sites in the NASA Micro-Pulse Lidar Network (MPLNET).
- MPL URL: <http://mplnet.gsfc.nasa.gov>

Description

The MPL was developed at GSFC during the early 1990s and is now a commercial product. MPL is a unique eye-safe lidar system that operates continuously (24 h/day) in an autonomous fashion. The capability of this lidar to operate unattended in remote areas makes it an ideal instrument to use for a network. In 2000, MPLNET was begun to provide long-term measurements of aerosol and cloud vertical structure. Lidar sites in MPLNET are co-located with Sun–sky photometer sites in the NASA Aerosol Robotic Network (AERONET). The combined measurements are able to produce quantitative aerosol and cloud products, such as optical depth, sky radiance, vertical structure, and extinction profiles. Over the past 10 years, MPL measurements have been conducted from urban locations, remote areas near desert regions and biomass burning zones, from

ships at sea, and even the South Pole. Data collected from around the globe has led to an increased understanding of aerosol properties and transport, aerosol–cloud interactions, and polar cloud and snow properties. MPLNET also serves as a ground-calibration network for several NASA satellite programs.

MPL Data Products

- Backscatter lidar signals from surface to 20+ km (1 min time resolution, 75 m vertical resolution)
- Calibrated attenuated backscatter profiles
- Aerosol extinction profiles
- Multiple cloud layer heights

MPL Parameters

- Laser wavelength: 523 nm
- Laser pulse energy: 5–10 μ J
- Pulse repetition rate: 2500 Hz
- Telescope: 7–8-in Cassegrain
- Vertical resolution: 30, 75, or 300 m
- Typical data rate: 1 s to 1 min

Principal Investigator

Ellsworth J. Welton
NASA Goddard Space Flight Center
Ellsworth.J.Welton@nasa.gov

Co-Investigators

Timothy A. Berkoff
University of Maryland Baltimore County

James R. Campbell
Science Systems and Applications, Inc.

Brent N. Holben
NASA Goddard Space Flight Center

James D. Spinhirne
NASA Goddard Space Flight Center

Si-Chee Tsay
NASA Goddard Space Flight Center

Scientific Questions for Future Observations

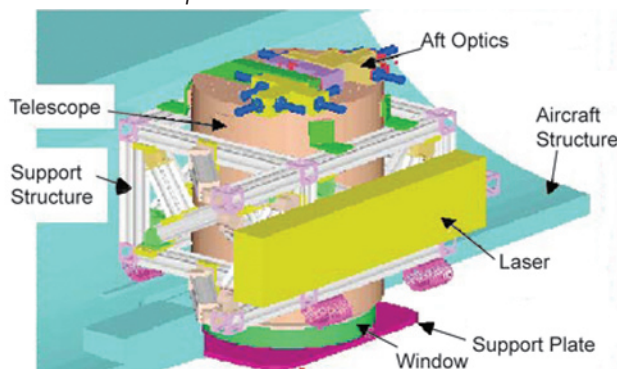
1. What are the altitudes of absorbing aerosol layers?
2. Can aerosol transport models accurately determine aerosol height?
3. What is the diurnal cycle of boundary layer height and how does it impact pollution levels near the surface?
4. How do dust, smoke, and pollution aerosols effect cloud formation and precipitation?
5. What are the optical properties of thin polar clouds and polar stratospheric clouds (PSC)?
6. What are blowing snow patterns like across Antarctica, and how do they compare to the Arctic?

References

- Ackerman, A.S., O.B. Toon, D.E. Stevens, A.J. Heymsfield, V. Ramanathan, and E. J. Welton, 2000: Reduction of tropical cloudiness by soot. *Science*, **288**, 1042–1047.
- Campbell, J.R., D.L. Hlavka, E.J. Welton, C.J. Flynn, D.D. Turner, J.D. Spinhirne, V.S. Scott, and I.H. Hwang, 2002: Full-time, eye-safe cloud and aerosol lidar observation at atmospheric radiation measurement program sites: Instrument and data processing. *J. Atmos. Ocean. Technol.*, **19**, 431–442.
- Colarco, P.R., M.R. Schoeberl, B.G. Doddridge, L.T. Marufu, O. Torres, and E.J. Welton, 2004: Transport of smoke from Canadian forest fires to the surface near Washington, D.C.: Injection height, entrainment, and optical Properties. *J. Geophys. Res.*, **109**, doi:10.1029/2003JD00428.
- Spinhirne, J.D., J. Rall, and V.S. Scott, 1995: Compact eye-safe lidar systems. *Rev. Laser Eng.*, **23**, 26–32.
- Welton, E.J., J.R. Campbell, J.D. Spinhirne, and V.S. Scott, 2001: “Global monitoring of clouds and aerosols using a network of micro-pulse lidar systems.” In: Lidar Remote Sensing for Industry and Environmental Monitoring, U.N. Singh, T. Itabe, and N. Sugimoto, Eds., *Proc. SPIE*, **4153**, 151–158.
- , K.J. Voss, P.K. Quinn, J.R. Campbell, J.D. Spinhirne, H.R. Gordon, and J.E. Johnson, 2002: Measurements of aerosol vertical profiles and optical properties during INDOEX 1999 using micro-pulse lidars. *J. Geophys. Res.*, **107D**, 18-1-18-20.

RASL

Raman Airborne Spectrometer Lidar



Concept drawing of RASL installation in aircraft

Key RASL Facts

- Heritage: GSFC Instrument Incubator Program (IIP) 2001
- Designed to measure water vapor mixing ratio, aerosol and cloud backscatter coefficients, the aerosol extinction coefficient, and the cloud liquid water content, depolarization, oxygen, and CO₂.
- The Laboratory tested and demonstrated all required capabilities in September 2002.
- Nominal field configuration: The system can be configured to fly in either the DC-8 or the P3 aircraft and requires a large 27-in window.
- RASL URL: <http://ramanlidar.gsfc.nasa.gov/index.htm>

Description

The system will perform daytime and nighttime measurements of water vapor mixing ratio, aerosol backscatter coefficient, extinction, and depolarization, extinction to backscatter ratio and liquid water scattering (night only). This system offers the possibility of retrieving cloud droplet properties such as liquid water content, droplet radius and number density. The all-reflective telescope can operate in any orientation relative to gravity. RASL is the only airborne lidar system to combine measurements of water vapor, aerosol backscatter, extinction, and depolarization and cloud liquid water. It also possesses a great advantage in eye safety over existing airborne water vapor lidar systems. It can also be configured as a CO₂ profiling airborne lidar. It is now being prepared for aircraft flight, which involves constructing the aircraft interface, as well as developing automated subsystems for laser power maintenance and bore-site alignment. The accompanying figure shows a preliminary drawing of RASL in the DC-8 cargo bay configuration.

RASL Data Products

- Water vapor mixing ratio
- Aerosol scattering ratio
- Aerosol extinction
- Aerosol backscattering coefficient

- Aerosol extinction/backscatter ratio
- Aerosol depolarization
- Cloud optical depth
- Cloud liquid water

RASL Parameters

- Laser wavelength: 355 nm
- Laser pulse energy: 350 mJ at 50 Hz
- Laser pulse length: 7 ns
- FOV: 25 μ rad, 0.6 m aperture
- Optical channels: 354.7, 375, 386.7, 403.2, and 407 nm

Principal Investigator

David N. Whiteman
NASA Goddard Space Flight Center
David.N.Whiteman@nasa.gov

RASL Team Members/Co-Investigators

Martin Cadirola
Electronic Systems, Ecotronics, Inc.

Joseph Comer
Science Systems and Applications, Inc.

Belay Demoz
NASA Goddard Space Flight Center

Keith Evans
University of Maryland Baltimore County

Antonia Gambacorta
University of Maryland Baltimore County

Gerry McIntyre
Raytheon Technical Services Company

Harvey Melfi
Raman Lidar Pioneer and Consultant

Felicita Russo
University of Maryland Baltimore County

Igor Veselovskii
University of Maryland Baltimore County

Zhien Wang
University of Maryland Baltimore County

Wayne Welch
Welch Mechanical Designs, LLC

Science Goals for Future Campaigns

1. Quantify the spatial variation of boundary-layer water vapor, aerosols, and clouds in mesoscale systems, such as fronts and bores.
2. Study the relationship of relative humidity on aerosol

- extinction within the boundary layer.
3. Investigate the relationship of aerosol extinction and cloud properties, such as liquid water content, droplet radius, and number density.
 4. Quantify cirrus cloud optical depth, equivalent particle size, and ice water content.

References

- Whiteman, D.N., G. Schwemmer, T. Berkoff, H. Plotkin, L. Ramos-Izquierdo, and G. Pappalardo, 2001: Performance modeling of an airborne Raman water vapor lidar. *Appl. Opt.*, **40**, 375–390.
- , K.D. Evans, B. Demoz, D. O’C. Starr, E. Eloranta, D. Tobin, W. Feltz, G. J. Jedlovec, S.I. Gutman, G.K. Schwemmer, M. Cadirola, S. H. Melfi, and F.J. Schmidlin, 2001: Raman lidar measurements of water vapor and cirrus clouds during the passage of hurricane Bonnie. *J. Geophys. Res.*, **106**, 5211–5225.

SRL

Scanning Raman Lidar



Picture of the SRL deployed at Andros Island, Bahamas during NOAA's Convection and Moisture Experiment (CAMEX-3).

Key SRL Facts

- Heritage: Marine boundary-layer lidar, 1985
- The SRL makes use of Raman scattering in the atmosphere to measure various atmospheric properties.
- Participated in the 2002 IHOP campaign in western Oklahoma.
- Nominal field configuration: All of the SRL instrumentation, including the laser, large aperture telescope, and data acquisition electronics, is housed within a single environmentally controlled mobile trailer, which also supplies workspace for several experimenters.
- SRL URL: <http://ramanlidar.gsfc.nasa.gov/index.htm>

Description

Water is the most active infrared molecule in the atmosphere; water vapor response is a major factor in any global warming triggered by increasing carbon dioxide. In addition, atmospheric aerosols have a significant impact on the Earth's climate by scattering and absorbing solar radiation and by altering the physical and radiative properties of clouds. The SRL was developed to provide frequent and accurate measurements of water vapor and aerosols to study these atmospheric processes. Laser scattering by water vapor, nitrogen, and oxygen molecules is detected as a function of altitude. The water vapor mixing ratio is computed from the ratio of the Raman scattering from water vapor and nitrogen. When combined with measurements of temperature, the lidar water vapor data gives profiles of relative humidity. When combined with measurements of temperature, the lidar water vapor data gives profiles of relative humidity. The lidar water vapor data acquired during field experiments have been used to validate radiative transfer models and study atmospheric features, such as fronts and gravity waves.

SRL Data Products

- Water vapor mixing ratio

- Aerosol scattering ratio
- Aerosol extinction
- Aerosol backscattering coefficient
- Aerosol extinction/backscatter ratio
- Aerosol depolarization
- Cloud optical depth
- Cloud liquid water

SRL Parameters

- Laser wavelength: 355 nm
- Laser pulse energy: 300 mJ
- Laser pulse length: 9 ns
- Laser pulse rate: 30 Hz
- Telescope aperture: 0.76 m
- FOV: 0.25 mrad
- Optical channels: 354.7, 375, 386.7, 403.2, and 407 nm

Principal Investigator

David N. Whiteman
NASA Goddard Space Flight Center
David.N.Whiteman@nasa.gov

SRL Team Members/Co-Investigators

Martin Cadirola
Electronic Systems, Ecotronics, Inc.

Joseph Comer
Science Systems and Applications, Inc.

Belay Demoz
NASA Goddard Space Flight Center

Keith Evans
University of Maryland Baltimore County

Antonia Gambacorta
University of Maryland Baltimore County

Gerry McIntyre
Raytheon Technical Services Company

Harvey Melfi
Raman Lidar Pioneer and Consultant

Felicita Russo
University of Maryland Baltimore County

Igor Veselovskii
University of Maryland Baltimore County

Zhien Wang
University of Maryland Baltimore County

Wayne Welch
Welch Mechanical Designs, LLC

Science Goals for Future Campaigns

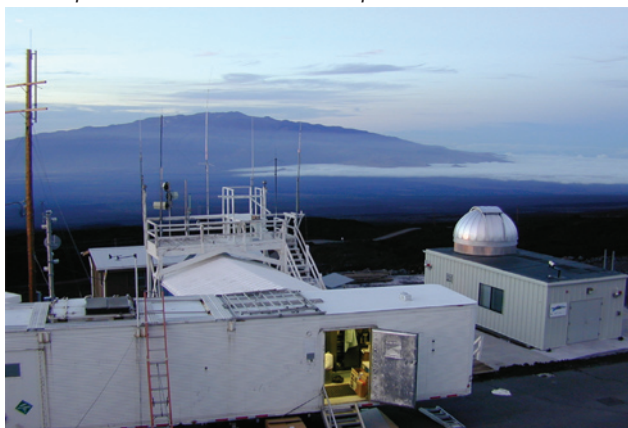
1. Quantify the spatial variation of boundary layer water vapor, aerosols, and clouds in mesoscale systems such as fronts and bores.
2. Study the relationship of relative humidity on aerosol extinction within the boundary layer.
3. Investigate the relationship of aerosol extinction and cloud properties such as liquid water content, droplet radius, and number density.
4. Quantify cirrus cloud optical depth, equivalent particle size, and ice water content.

References

- Whiteman, D.N., 2003: Examination of the traditional Raman lidar technique. I. Evaluating the temperature-dependent lidar equations. *Appl. Opt.*, **42**, 2571–2592.
- , 2003: Examination of the traditional Raman lidar technique. II. Evaluating the ratios for water vapor and aerosols. *Appl. Opt.*, **42**, 2593–2608.

STROZ LITE

Stratospheric Ozone Lidar Trailer Experiment



The STROZ LITE Trailer deployed at the Mauna Loa Observatory in August 2002. Mauna Kea is visible in the background.

Key STROZ LITE Facts

- Heritage: Originally designed for stratospheric ozone, modified to include temperature, aerosols, and tropospheric water vapor.
- A differential absorption, elastic and inelastic backscatter lidar instrument that returns vertical profiles of ozone, temperature, and aerosol parameters in the stratosphere, and a vertical profile of water vapor in the troposphere.
- The lidar has been involved in 18 national and international campaigns supporting satellite validation, aircraft campaigns, and NDSC validation campaigns.
- Nominal field configuration: The system is mobile and is housed in a large, environmentally controlled shipping container.

Description

The STROZ LITE lidar uses two lasers to generate the two wavelengths that are transmitted into the atmosphere: an XeCl excimer laser, emitting at 308 nm; and another laser to transmit near 350 nm with a spectrally narrow emission line. Ozone is extracted using a Differential Absorption (DIAL) technique: two wavelengths are transmitted into the atmosphere. One is strongly absorbed by ozone, while the other is not absorbed. Ozone can then be deduced from the difference in slope between the lidar returns at the two transmitted wavelengths. In addition to collecting the backscatter signal from each of these transmitted wavelengths, STROZ LITE collects several inelastic returns from Raman scattering from N_2 and H_2O . The STROZ LITE instrument was the first to develop the Raman scatter differential absorption technique for the measurement of ozone profiles in the presence of heavy aerosol loadings. This was put into place shortly after the eruption of Mt. Pinatubo in 1991. The suc-

cess of this technique resulted in a recommendation from the NDSC Steering Committees that all ozone lidar instruments within the NDSC should incorporate the Raman channels needed for the Raman DIAL technique.

STROZ LITE Data Products

- Aerosol backscatter at 355 nm
- Aerosol backscatter and extinction at 355 nm
- Stratospheric and mesospheric temperature
- Tropospheric water vapor
- Stratospheric ozone

STROZ LITE Parameters

- Laser wavelengths: 308 nm at 200Hz; 355 nm at 50 Hz
- Optical returns: 308, 332, 355, 387, 407 nm
- Vertical resolution (raw signal): 15 m
- Telescope: 30-in Dall-Kirkham

Principal Investigator

Thomas J. McGee
NASA Goddard Space Flight Center
Thomas.J.McGee@nasa.gov

Co-Investigators

Paul Newman
NASA Goddard Space Flight Center

Donald Silbert
NASA Goddard Space Flight Center

Grant Sumnicht
Science Systems and Applications, Inc.

Laurence Twigg
Science Systems and Applications, Inc.

Science Questions for Future Campaigns

1. Has ozone begun its recovery from the losses because of Cl destruction?

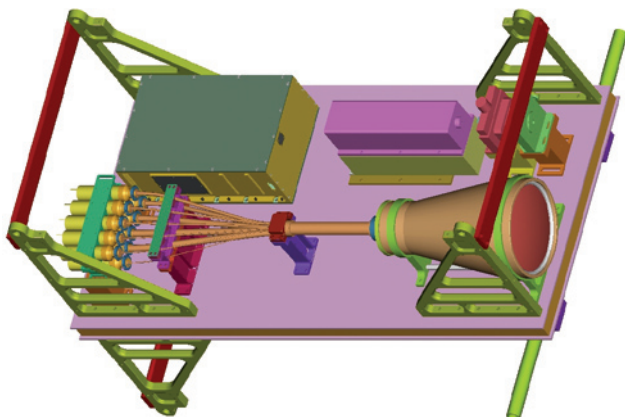
References

- Bailey, P.L., D.P. Edwards, J.C. Gille, L.V. Lyjack, S.T. Massie, A.E. Roche, J.B. Kumer, J.L. Mergenthaler, B.J. Connor, M.R. Gunson, J.J. Margitan, I.S. McDermid, and T.J. McGee, 1996: Comparison of Cryogenic Limb Array Etalon Spectrometer (CLAES) ozone observations with correlative measurements. *J. Geophys. Res.*, **101**, 9737–9756.

- , and —, 1996: Comparison of Cryogenic Limb Array Etalon Spectrometer (CLAES) ozone observations with correlative measurements. *J. Geophys. Res.*, **101**, 9737–9756.
- McGee, T.J., M. Gross, U.N. Singh, J.J. Butler, and P. Kimvilakani, 1995: An improved stratospheric ozone lidar. *Opt. Eng.*, **34**, 1421–1430.
- , —, —, P. Kimvilakani, A. Matthews, G. Bodeker, B. Connor, J.J. Tsou, M. Proffitt, and J. Margitan, 1997: Lidar measurements of ozone at Lauder, NZ during ASHOE/MAESA. *J. Geophys. Res.-Atmos.*, **102**, 13,283–13,289.
- Steinbrecht, W., R. Neuber, P. von der Gathen, P. Wahl, T. McGee, M. Gross, U. Klein, and J. Langer, 1999: Results of the 1998 Ny-Ålesund ozone monitoring comparison. *J. Geophys. Res.*, **104**, 30,515–30,523.

THOR

cloud Thickness from Offbeam Returns



THOR digital image courtesy of Welch Mechanical Designs, LLC (P3 optical bench configuration).

Key THOR Facts

- Heritage: 1996–2000 DDF
- Off-beam lidar using pulsed laser beam to measure diffusing wave propagation in dense clouds to determine optical and geometrical properties. A unique focal plane consists of 250,000 fiber filaments arranged into eight annular rings.
- Instrument validation campaign completed in 2002 over the DOE ARM site in northern Oklahoma.
- Nominal flight characteristics: 5 km above cloud tops; duration typically 8 h.
- THOR URL: <http://climate.gsfc.nasa.gov/Lidar>

Description

The physical thickness of a cloud layer, and sometimes multiple cloud layers, can be estimated from the time delay of off-beam returns from a pulsed laser source illuminating one side of the cloud layer. In particular, the time delay of light returning from the outer diffuse halo of light surrounding the beam entry point, relative to the time delay at beam center, determines the cloud physical thickness. The delay combined with the pulse stretch gives the optical thickness. The halo method works best for thick cloud layers, typically optical thickness exceeding 2, and thus compliments conventional lidar, which cannot penetrate thick clouds. The THOR System flies on the NASA P3, and measures the halo timings from several kilometers above cloud top, at the same time providing conventional lidar cloud top height. A refractive telescope with approximately a 7.5-in (19.05 cm) aperture is used to gather the returned light and collect it into a custom designed fiber optic bundle. The fiber optic bundle routes specific sections of the light, focused by the telescope, into 10 Hamamatsu detectors.

THOR Data Products

- Cloud top and cloud base height

- Vertical scattering extinction profile
- Optical thickness
- Sea ice thickness
- Sea ice scattering and extinction profile

THOR Parameters

- Laser wavelength: 540 nm
- FOV: 6°
- Laser pulse energy: 200 μ J
- Laser pulse rate: 1 kHz

Principal Investigator

Robert F. Cahalan
NASA Goddard Space Flight Center
Robert.F.Cahalan@nasa.gov

Co-Investigators

John Kolasinski
NASA Goddard Space Flight Center

Matthew J. McGill
NASA Goddard Space Flight Center

THOR Team Members

John Kolasanski
NASA Goddard Space Flight Center

Matthew J. McGill
NASA Goddard Space Flight Center

Luis A. Ramos-Izquierdo
NASA Goddard Space Flight Center

Tamas Varnai
University of Maryland Baltimore County

Wayne Welch, Mechanical Engineer
Welch Mechanical Designs, LLC

Ken Yetzer
Raytheon Technical Services Company

Science Questions for Future Campaigns

1. How does sea ice thickness vary for different ice types, locations and seasons?
2. How will Cryosat's estimates of sea ice thickness be affected by small-scale variations seen by THOR?
3. What is the vertical profile of cloud scattering extinction, particle size and absorption?

Future Campaigns

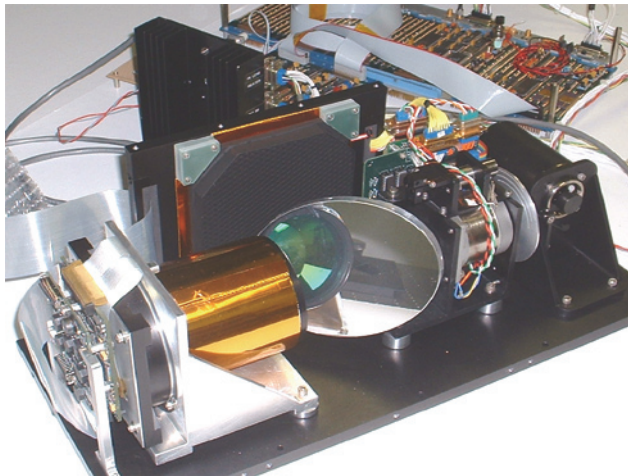
South Pole experiment, September 6, 2004, AASI (Antarctic AMSR-E Sea Ice Mission)

PASSIVE OPTICAL INSTRUMENT SYSTEMS



COVIR

Compact Visible and Infrared Radiometer



This instrument is intended to provide global cloud cover measurements with high accuracy and improved spatial resolution. By an innovative use of uncooled array detectors, the instrument measures both spectral radiance and stereo spatial information. The stereo infrared cloud retrievals will be unbiased by day–night illumination variation.

Key COVIR Facts

- Heritage: Infrared Spectral Imaging Radiometer (ISIR) flown on STS-85
- A small, lightweight, low-power, and low-cost visible and thermal, infrared imaging employing uncooled infrared detectors.
- Nominal orbit characteristics: Low-Earth orbit satellite or on a space shuttle mission.
- COVIR URL: <http://isir.gsfc.nasa.gov/>

Description

COVIR is currently developed as an engineering model of an imaging radiometer for small satellite missions. The instrument measures one visible and four infrared wavelengths, and uniquely employs uncooled microbolometer array focal plane detectors. The system design emphasizes accurate measurement of the thermal brightness temperature of clouds at high spatial resolution and at several wavelengths to obtain the spatial extent of clouds and retrievals of height distribution, particle size, and other parameters. Data will be used to model and better understand the role of clouds in the Earth's radiation budget. An important goal of COVIR is to make future multisensor Earth science missions possible on small satellite platforms. This could lead to improved cloud sensing through an increased number of platforms with sensors advanced in spectral coverage and resolution.

COVIR consists of subsystems including an infrared camera, a visible camera, an electronics box, a mirror assembly, and a blackbody calibration source. The infrared camera (IC) consists of an infrared lens triplet, a 240×320 pixel microbolometer array, a thermoelectric cooler for tempera-

ture stabilization, four strip filters and electronics that are responsible for signal conditioning, analog-to-digital conversion and gain/offset correction. The design of COVIR is complete and testing is ongoing. An additional unique application of the infrared imaging mode is direct stereo cloud height retrievals. Analysis was completed and a paper was published on the results of infrared stereo cloud height retrieval by data acquired during the ISIR shuttle hitchhiker experiment. This is an important application of COVIR, and the results show very good promise.

COVIR Data Products

- Multispectral visible and infrared radiometrically calibrated radiances

COVIR Parameters

- Wavelengths: 0.8–0.9, 3.55–3.95, 10.3–11.3, and 11.5–12.5 μ
- Spatial resolution: 0.5 km
- Swath: 90–190 km
- Mass: 10 kg
- Power: 15 W
- Temperature resolution: 0.1 K
- Channels: 1 visible and 4 infrared

Principal Investigator

James Spinhirne
NASA Goddard Space Flight Center
James.Spinhirne@nasa.gov

Co-Investigators

Redgie Lancaster
NASA Goddard Space Flight Center

Ashwin Mahesh
University of Maryland Baltimore County

Katherine Manizade
University of Maryland Baltimore County

COVIR Team Members (all from NASA GSFC)

Troy Ames
Rene Carlos
John Cavanaugh
George Daelemans
Bruce Dean
Ashok Desai
Betsy Forsbacka
Tom Hartmann
Carlos Hernandez
Rusty Jones
Rich Katz
Cindy Kirchner
Claudia Leboeuf
Sridhar Manthripragada
Eric Mentzell

James Parker
 Tony Sanders
 Bill Schaefer
 Jeff Travis
 Mark Wilson

References

Science Goals for Future Missions

1. Global cloud coverage and height distribution
2. Cloud microphysical phase and size distribution
3. Cloud ice/water content distribution
4. Cloud feed backs

Future or Related Missions

- Projected for Global Precipitation Measurement (GPM) Instrument of Opportunity
- Planned Earth System Science Pathfinder (ESSP) cloud proposal

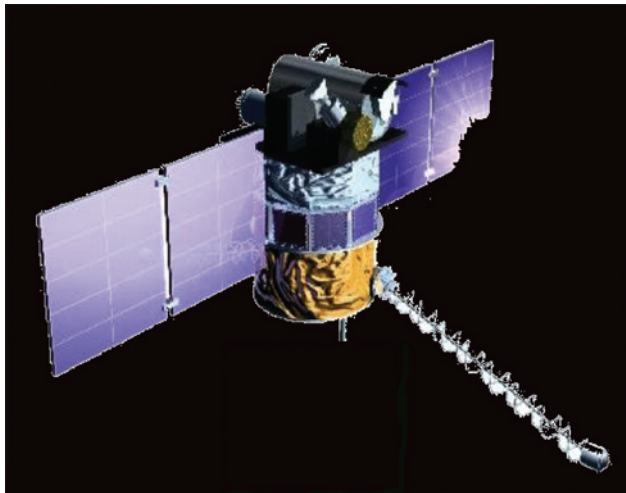
Lancaster, R.S., J.D. Spinhirne, K. Manizade, S.P. Palm, and V.S. Scott, 2001: The Compact Visible and Infrared Radiometer (COVIR) for Earth and climate monitoring. *IEEE Aerospace 2001 Proc.*, Big Sky, Montana, doi: 10.1109/AERO.2001.931479, **4**, 1719–1727.

—, —, and —, 2003: Combined infrared stereo and laser ranging cloud measurements from shuttle mission STS-85. *J. Atmos. Ocean. Tech.*, **20**, 67–78.

Spinhirne, J.D., R. Lancaster, and K. Maschhoff, 2001: Application and design of satellite infrared spectral imaging radiometers with uncooled microbolometer array detectors. *AMS 11th Conf. Satellite Meteor. Oceanog.*, Poster Session, Madison, Wisconsin.

EPIC

Earth Polychromatic Imaging Camera on the DSCOVR Observatory Project



Drawing of the completed Earth-viewing Deep Space Climate Observatory (DSCOVR) Project (formerly Triana) spacecraft and instruments that were scheduled for launch and deployment to the Earth's Lagrange-1 point.

Key EPIC Facts

- Heritage: An improved version of the Triana spectroradiometer EPIC.
- EPIC is a 10-channel spectroradiometer spanning the ultraviolet to the near-infrared, 317.5–905 nm simultaneously imaging the Earth, from pole to pole and from sunrise to sunset, once per hour.
- Nominal orbit characteristics: Six-month orbit about the Lagrange-1 (L1) point, or neutral gravity point between the Earth and the Sun. The mission is awaiting a launch opportunity.
- EPIC URL: <http://triana.gsfc.nasa.gov/>

Description

EPIC is designed to observe the entire daylight side of the Earth from sunrise to sunset and pole-to-pole using a 10-channel spectroradiometer with 10 km resolution. EPIC has two unique characteristics: (1) the first spaceborne measurements from sunrise to sunset of the entire sunlit Earth, and (2) the first synoptic measurements in both the ultraviolet and visible wavelengths for the entire Earth. These capabilities will allow the determination of diurnal variations of ozone, SO₂, smoke, dust, pollution, water vapor, land and ocean characteristics (ocean color), vegetation index, bidirectional reflectivity (hotspot analysis), and cloud properties. The applications to human health include knowledge and prediction of ultraviolet exposure and identification of high-exposure high-risk regions, detection and avoidance of smoke plumes from forest fires throughout the daylight hours, detection of floodwaters, and large-scale vegetation changes from drought and land-use changes. The in-storage

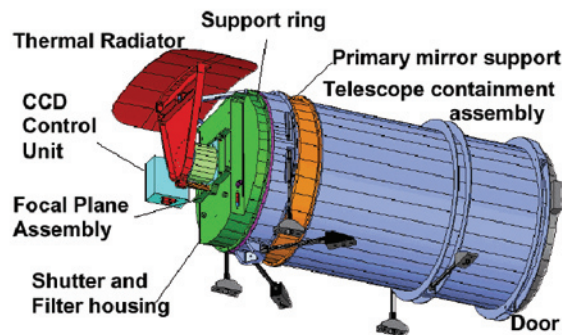
DSCOVR/EPIC spacecraft and instruments are complete and tested for flight.

EPIC Data Products

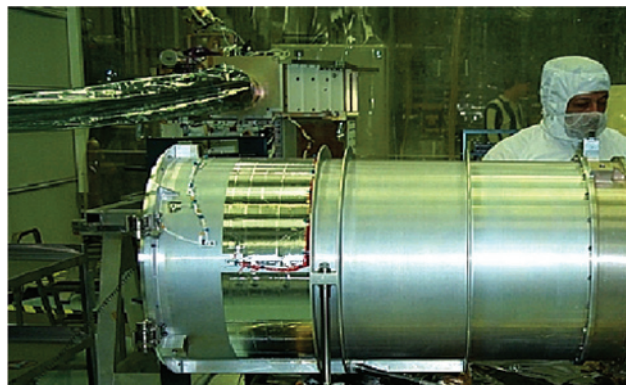
- Column ozone: hourly
- Aerosols (dust, smoke, volcanic ash, and sulfate pollution): hourly
- Sulfur dioxide: hourly
- Perceptible water: hourly
- Cloud height, cloud reflectivity, cloud phase (ice or water): every 15 min
- Ultraviolet radiation: every 15 min
- Cloud phase (ice crystal formation)

EPIC Parameters

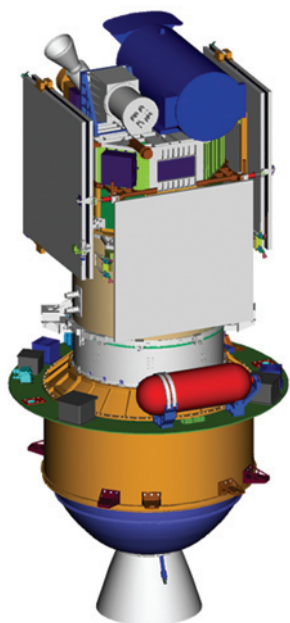
- Wavelengths: 317.5, 320, 340, 388, 443, 551, 645, 870, and 905 nm
- Spatial resolution: 8–10 km
- Size: 0.4 m × 2 m
- Mass: 75 kg
- Power: 83 W
- Aperture: 30 cm



View of the EPIC spectroradiometer showing the external housing for the 30 cm telescope and the thermal radiator attached to the charge coupled device (CCD) housing to keep the CCD at about -40°C. The six struts are for attachment to the spacecraft.



Photograph of EPIC showing the external housing.



Principal Investigator
Francisco P.J. Valero
Scripps Institution of Oceanography
fvalero@ucsd.edu

Project Scientist
Jay R. Herman
NASA Goddard Space Flight Center

Assembled EPIC spectrometer prior to mounting on the DSCOVR spacecraft.

SMART

Surface-Sensing Measurements for Atmospheric Radiative Transfer



The SMART trailer is the Laboratory's first mobile lab, which hosts an array of remote sensing instruments.

Key SMART Facts

- Nominal field configuration: Ground-based station with many global, diffuse, and direct broadband radiometers (Fig. a); sun/sky/surface photometers and a shadow-band radiometer (Fig. b); a spectroradiometer (Fig. c); a whole sky imager, a micro-pulse lidar, and an interferometer (Figs. d, e, and f); a scanning microwave radiometer with a physical and optical rain gauge and meteorological sensors (Figs. g, h, i, and j); and several data loggers and a local computer network operating inside the trailer (Figs. k and l).
- EPIC URL: <http://smart-commit.gsfc.nasa.gov/>

Description:

The instrument list grew from a micro-pulse lidar, a sun photometer and five broadband radiometers in 1998, to more than two-dozen devices covering a wide spectral range—from ultraviolet, visible, near-infrared, shortwave-infrared, and longwave-infrared, to microwave. As the suite evolves, all the instruments are integrated into a 20-ft weather-sealed trailer with a thermostatic temperature control to facilitate the shipping to, and operation in, the field.

SMART has been deployed in many international and domestic field experiments. Many unique data sets have been generated for ground-based remote sensing studies in atmospheric sciences.

A companion *in situ* measurement package is built to form the SMART-COMMIT¹ mobile laboratories.

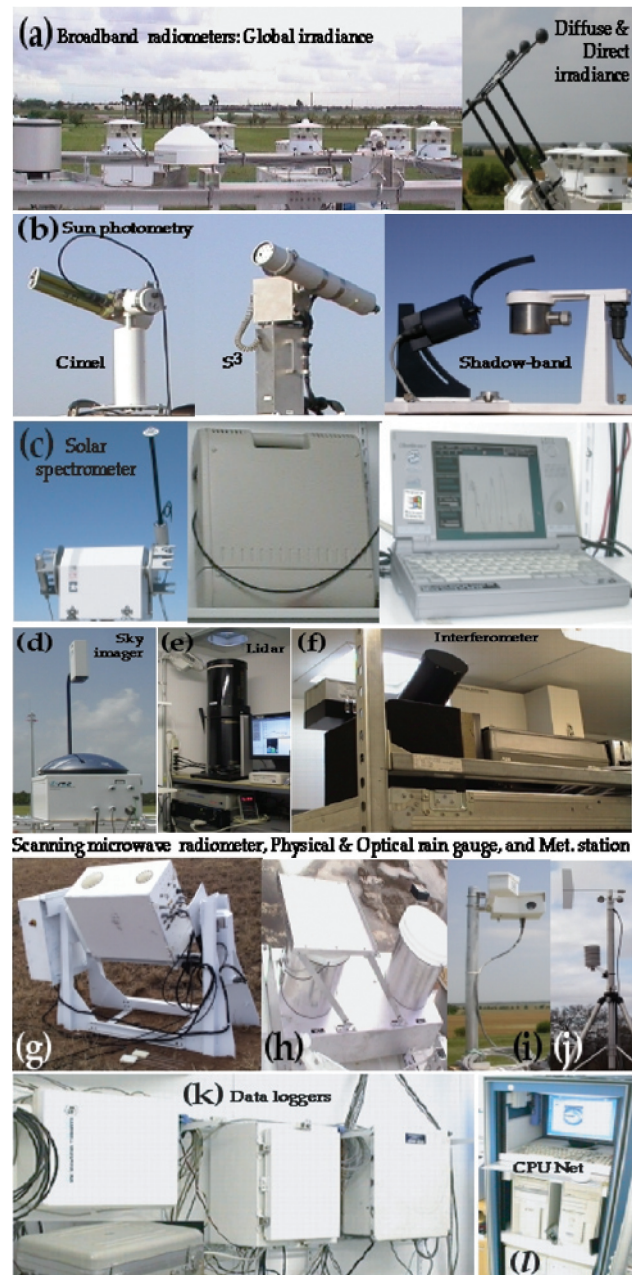
The SMART-COMMIT mission is designed to pursue the following goals:

- EOS validation

- Innovative investigations
- Long-term atmospheric monitoring

SMART Data Products

- Global, diffuse, and direct solar irradiance with various bands of energy partitioning
- Global sky longwave-infrared irradiance
- Transmitted and sky-solar spectral radiance and various narrow-band radiance at atmospheric window regions
- Emitted downwelling infrared radiance
- Microwave downwelling sky radiance
- Normalized backscatter intensity
- Total sky imagery
- Meteorological conditions near the ground



SMART Parameters

- Broadband wavelengths: 0.3~3, 0.4~3, 0.7~3, and 4~50 μm (global, diffuse, and direct component)
- Narrowband wavelengths: 302, 308, 315, 336, and 377 nm (global); 414, 498, 614, 672, 866, and 939 nm (global and diffuse); 340, 380, 440, 500, 670, 870, 870 nm horizontally polarized, 870 nm vertically polarized, 940, 1020, 1240, 1440, and 2130 nm (direct)
- Laser frequency: 532 nm
- Shortwave spectra: 0.35~2.5 μm
- Longwave spectra: 3~20 μm
- Microwave: 23, 36, and 90 GHz
- Sky image: red, green, and blue (RGB)

- Meteorological parameters: pressure (P), temperature (T), relative humidity (RH), wind direction and speed (u , v , respectively)

SMART Team Members

Qiang Ji
University of Maryland College Park

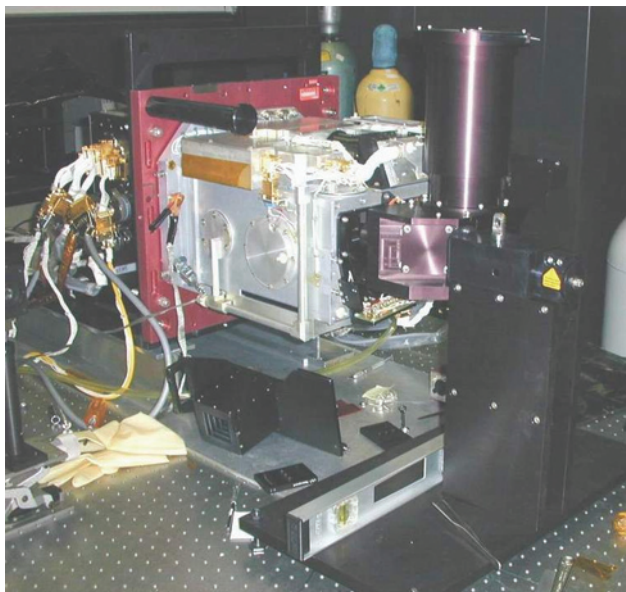
Si-Chee Tsay
NASA Goddard Space Flight Center

Endnote:

1. COMMIT: Chemical Optical, and Microphysical Measurements of *In situ* Troposphere.

SSBUV

Shuttle Solar Backscatter Ultraviolet



SSBUV with the Skyrad telescope in the Radiometric Calibration and Development Facility (RDCF).

Key SSBUV Facts

- Heritage: SBUV/2 on NOAA/POES
- SSBUV is a refurbished Solar Backscatter Ultraviolet (SBUV/2) instrument of the type flown on the NOAA Polar Orbiting Environmental Satellite (POES). The instrument is a scanning double Ebert-Fastie holographic spectrometer with 1.1 nm bandpass operating from 240–405 nm.
- SSBUV flew eight times on the Space Shuttle between 1989 and 1996 and under-flew NOAA-9 and -11 providing calibration checks by comparing normalized radiances (radiance/solar irradiance) from 240–400 nm. SSBUV also conducted intercomparison flights with the solar ultraviolet spectral irradiance instruments flying on the Upper Atmosphere Research Satellite (UARS).
- SSBUV is permanently located at the GSFC RDCF.
- SSBUV URL: <http://ventus.gsfc.nasa.gov/>

Description

SSBUV with RDCF radiometric resources provide prelaunch calibration support for all U.S. and international backscatter ultraviolet and visible satellite instruments measuring ozone, aerosol, and trace gases. These instruments include TOMS, SBUV/2, GOME, SCIAMACHY, OSIRIS, OMI, and GOME-2. Calibration of OMPS flying on NPP and NPOESS is planned.

The RDCF provides a clean-room environment for SSBUV, but allows observations of the zenith sky through a pressurized view port open to the sky, which ensures maintenance of high radiometric accuracy using standards and procedures

coordinated by the National Institute of Standards and Technology (NIST).

Nearly two years of zenith sky data have been taken under a range of sky conditions. These data were compared to theoretical radiances calculated for conditions over GSFC including a range of aerosol characteristics and ozone amounts. Comparisons of observations and model show differences of less than 3%.

SSBUV Applications

- Prelaunch calibrations for all satellite ozone instruments using ultraviolet and visible backscatter techniques.
- Zenith sky observations for refining radiative transfer models, developing satellite algorithms, and observing ozone and aerosols in the stratosphere

Principal Investigator

Ernest Hilsenrath
NASA Goddard Space Flight Center
Ernest.Hilsenrath@nasa.gov

SSBUV Team Members/Co-Investigators

Bojan Bojkov
Science Systems and Applications, Inc.

Scott Janz
NASA Goddard Space Flight Center

Matt Kawalewski
Science Systems and Applications, Inc.

Gordon Labow
Science Systems and Applications, Inc.

Science Questions for Future Campaigns

1. How can ozone trends be accurately tracked using multiple satellite instruments? Can errors in algorithms and calibrations be separated?
2. How do ultraviolet absorbing aerosols impact climate?
3. Backscatter ultraviolet/visible measurements of ozone and trace gases?
4. How do ultraviolet absorbing aerosols contribute to climate forcing?

Future Observations

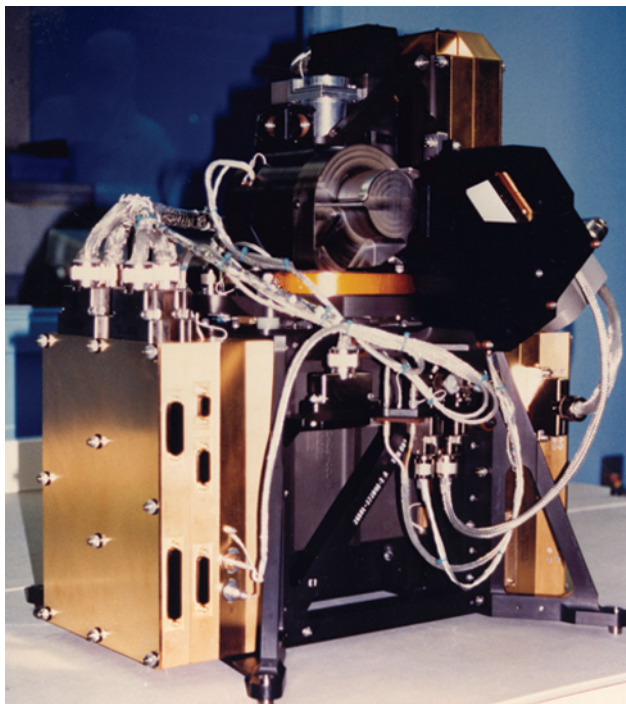
- Calibration of NPOESS ozone monitoring instrument (OMPS)
- Validation of Envisat SCIAMACHY and Aura OMI instruments
- Continued zenith sky observations (Skyrad) for research on ultraviolet radiative transfer models and trace gas algorithms

References

- Cebula, R.P., and E. Hilsenrath, 1990: Prelaunch calibration of the Shuttle Solar Backscatter Ultraviolet (SSBUV) spectrometer for STS-34, optical remote sensing of the atmosphere. Optical Society of America. *1990 Technical Digest Series*, **4**, 548–551.
- Deland, M.T., R.P. Cebula, and E. Hilsenrath, 2004: Observations of solar spectral irradiance change during cycle 22 from NOAA-9 SBUV/2. *J. Geophys. Res.*, **109**, D06304, doi: 10.1029/2003JD004074.
- Hilsenrath, E., R.P. Cebula, and C.H. Jackman, 1992: Ozone depletion in the upper stratosphere estimated from satellite and space shuttle data. *Nature*, **358**, 131–133.
- , P.A. Newman, R.P. Cebula, P.W. DeCamp, T.J. Kelly, and L. Coy, 1996: Ozone change from 1992 to 1993 as observed from SSBUV on the Atlas-1 and Atlas-2 missions. *Geophys. Res. Lett.*, **23**, 2305–2308.
- , P.K. Bhartia, R.P. Cebula, and C.G. Wellemeyer, 1997: Calibration and intercalibration of Backscatter Ultraviolet (BUV) satellite ozone data. *J. Adv. Space Res.*, **19**, 1345–1353.
- Janz, S. J., E. Hilsenrath, J. Butler, D. F. Heath and R. P. Cebula, 1996: Uncertainties in radiance calibrations of Backscatter Ultraviolet (BUV) instruments. *Meteorologia*, **32**, 637–641.

TOMS

Total Ozone Mapping Spectrometer



Earth-Probe (EP) TOMS Instrument.

Key TOMS Facts

- Heritage: Nimbus-4 BUUV spectrometer operating in the 250–380 nm range.
- TOMS provides daily mapping, and long-term trend determination of ozone, aerosols, and ultraviolet irradiances.
- Nominal orbit characteristics: circular, polar, sun-synchronous, altitude 955 km, inclination 99.3°, equator crossing time of 12 noon.
- TOMS URL: <http://toms.gsfc.nasa.gov>

Description

For the last 25 years, NASA's TOMS instruments have been looking at the Earth and making daily maps of the ozone content of the atmosphere across the globe, showing scientists the evolution of the global ozone and the ozone hole from 1979 to today. This data was an essential factor in establishing international agreements that banned ozone-destroying chlorofluorocarbons and halogens. Years of TOMS measurements and studies have led to new capabilities and applications for this instrument: detection of desert dust and biomass burning aerosols, detection of sulfur dioxide and ash from volcanic eruptions, measurements of low level ozone or smog, and measurements of ultraviolet radiation at Earth's surface.

EP TOMS Data Products

- Global daily ozone
- Global daily aerosols

- Global daily surface ultraviolet
- Tropospheric column ozone
- Volcanic SO₂ and ash

Current EP TOMS Low-Orbit Parameters

- Altitude: 740 km
- Inclination: 98.385°
- Period: 99.65 min
- FOV at nadir: 39 km × 39 km
- Mass: 34 kg
- Max. Scan Angle: ± 51°
- Peak Power: 66.6 W

Project Scientist

Pawan K. Bhartia
NASA Goddard Space Flight Center
Pawan.K.Bhartia@nasa.gov

Principal Investigator

Richard McPeters
NASA Goddard Space Flight Center
Richard.D.McPeters@nasa.gov

TOMS Team Members

Kelley Chance
Harvard Smithsonian

Sushil Chandra
NASA Goddard Space Flight Center

Jack Fishman

NASA Langley Research Center

Ben Herman
University of Arizona

Jay Herman
NASA Goddard Space Flight Center

Lon Hood
University of Arizona

Robert Hudson
University of Maryland

Arlin Krueger
NASA Goddard Space Flight Center

Steve Lloyd
Johns Hopkins Applied Physics Laboratory

Ken Minschwaner
New Mexico Institute of Mining and Technology

Michael Newchurch
University of Alabama, Huntsville

Sam Oltmans
NOAA/CMDL

Joseph Prospero
University of Miami

John Stanford
Iowa State University

Richard Stolarski
NASA Goddard Space Flight Center

Anne Thompson
NASA Goddard Space Flight Center

Yuk Yung
California Institute of Technology

Science Questions for Future Missions

1. Is the ozone layer recovering?
2. What are the sources of aerosols and trace gases that affect global air quality and how are they transported?
3. What are the roles of tropospheric ozone and aerosols in climate change?
4. What are the causes of surface ultraviolet change?
5. What are the short-term temporal changes in ozone and aerosols?
6. What are the diurnal changes in tropospheric ozone and aerosols (i.e., daytime to nighttime)?

Future or Related Missions

- Aura OMI: 2004
- NPOESS OMPS: 2009

References

- Herman, J. R., R. Hudson, R. McPeters, R. Stolarski, Z. Ahmad, X-Y Gu, S. Taylor, and C. Wellemeyer, 1991: A new self-calibration method applied to TOMS/SBUV backscattered ultraviolet data to determine long-term global ozone change. *J. Geophys. Res.*, **96**, 7531–7545.
- , —, —, —, and —, 1991: Global average ozone change from October 1978 to May 1990. *J. Geophys. Res.*, **96**, 17,297–17,305.
- , P.A. Newman, and D. Larko, 1995: Meteor-3/TOMS observations of the 1994 ozone hole. *Geophys. Res., Lett.*, **22**, 3227–3229.
- , P.K. Bhartia, J. Ziemke, Z. Ahmad, and D. Larko, 1996: UV-B radiation increases (1979–1992) from decreases in total ozone. *Geophys. Res., Lett.*, **23**, 2117–2120.
- Stolarski, R.S., A.J. Krueger, M.R. Schoeberl, R.D. McPeters, P.A. Newman, and J.C. Alpert, 1986: Nimbus 7 satellite measurements of the springtime Antarctic ozone decrease. *Nature*, **322**, 808–811.
- Torres, O., J.R. Herman, P.K. Bhartia, and A. Sinyuk, 2002: A long-term record of aerosol optical thickness from TOMS observations and comparison to AERONET measurement. *J. Atmos. Sci.*, **59**, 398–413.

***IN SITU* INSTRUMENT SYSTEMS**



COMMIT

Chemical, Optical, and Microphysical Measurements of In situ Troposphere



The COMMIT trailer is the Laboratory's second mobile lab, which will be the home of our in situ instruments for measuring atmospheric aerosol's physical, optical, and chemical properties.

Key COMMIT Facts

- Heritage: Extending the success of the mobile ground-based remote-sensing facility, SMART, this mobile ground-based suite for *in situ* measurements is built for studying major basic chemical, optical, and microphysical properties of atmospheric aerosols and trace gases.
- All the instruments are integrated in a 20-ft weather-sealed trailer with thermostatic temperature control, which is similarly configured as the SMART trailer. These two mobile laboratories can be deployed and operated either together or individually.
- Normal field configuration: COMMIT is a ground-based station with a stack as the inlet to draw sample air from 10 m above the ground into a dehumidifying system to dry the sample parcel. It then branches out to several instruments: an ambient particle monitor for particle mass concentration (Fig. a); two particle sizers for particle size distribution (Figs. b–c); a three-wavelength integrating nephelometer for particle light scattering properties in visible light (single wavelength nephelometers for particle light scattering at different relative humidity, Fig. e); and four gas analyzers for the concentration of nitrogen monoxide/dioxide, sulfur dioxide, carbon monoxide, and ozone (Fig. f).
- COMMIT URL: <http://smart-commit.gsfc.nasa.gov/>

COMMIT Data Products

- Aerosol particle mass concentration
- Aerosol particle size distribution
- Aerosol light scattering coefficient
- Trace gas concentration

COMMIT Parameters

- Aerosol particle mass concentration with size cut at PM-10 (in micrometers), PM-2.5, and PM-1
- Aerosol aerodynamic size distribution: 0.02–1.0 μm
- Aerosol aerodynamic size distribution: 0.5–15 μm
- Aerosol scattering coefficient at 450, 550, and 700 nm
- Aerosol scattering coefficient at 530 nm, for dry sample air, aerosol at the ambient and at a higher relative humidity
- Gas concentration: NO/NO₂, SO₂, CO, O₃



COMMIT Team Members

Qiang Ji
Earth System Science Interdisciplinary Center

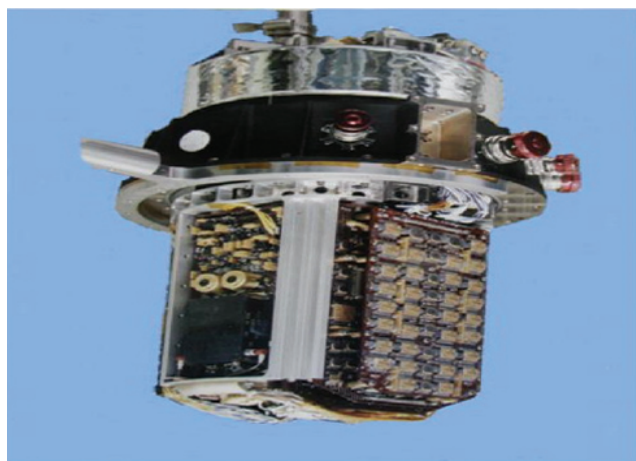
Si-Chee Tsay
NASA Goddard Space Flight Center

Science Questions for Future Campaigns

1. How are the chemical and microphysical properties of aerosol particles linked to their optical properties?
2. How are the aerosol particles near the ground related to those aloft?
3. Can we better quantify the aerosol indirect effect to the climate?

GCMS

Gas Chromatograph Mass Spectrometer



GCMS shown without upper and lower experiment housing. The inlet system is shown at top of picture and the electronics are shown at the bottom. The height of the experiment housing is 45 cm and the diameter is 18 cm.

Key GCMS Facts

- Heritage: Galileo Probe Mass Spectrometer
- Nominal orbit characteristics: The Huygens Probe will separate from the Saturn Orbiter approximately 1200 km above the surface of Titan. The GCMS will begin operating approximately 170 km above the surface of Titan.
- GCMS URL: <http://HuygensGCMS.gsfc.nasa.gov>

Description

The Cassini mission to Saturn is a joint effort of NASA and the European Space Agency. The Cassini mission includes a Saturn Orbiter developed by NASA and the Huygens Probe, which was developed by the European Space Agency. The probe will investigate the atmosphere of Titan, one of Saturn's moons. The GCMS for the Huygens Probe was developed and built by the Laboratory. Cassini will travel 2 billion miles to reach Saturn, and another 1.1 billion miles while in orbit around Saturn. In order to investigate the chemical composition of Titan, the GCMS samples gas directly from the atmosphere as the Probe descends through the atmosphere.

The GCMS will continuously measure the atmospheric composition and the isotope ratios of the major gaseous constituents from about 170 km altitude until the probe reaches the surface. At least four gas chromatograph samples will be taken at various altitudes during the descent. The GCMS will also analyze gas samples from a French experiment—the Aerosol Collector Pyrolyzer (ACP). The ACP will generate gases from the thermal decomposition of atmospheric aerosols in an oven, and the gases will then be transferred to the GCMS for analysis. Once the probe reaches the surface of

Titan, the GCMS will continue to operate and should obtain compositional measurements of the surface material.

The 319 kg (703 pound) Huygens Probe separated from the Cassini Orbiter on December 25, 2004, and began a 22-day coast phase toward Titan. On January 14, 2005, just 45 min before reaching the atmosphere of Titan, timers were activated onboard the Huygens Probe. As it entered Titan's atmosphere, three sets of parachutes slowed down the Probe and provided a stable platform for scientific measurements. The fully instrumented robotic laboratory reached the mysterious Titan surface about 2.5 h later.

GCMS Data Products

- Atmospheric composition: Abundance of all constituents within a mass range of 2–141 Da with mixing ratios $>10^{-8}$, and selected species to 10^{-10} . The variation of CH_4 with altitude and the discrimination between CO and N_2 .
- Atmospheric origin and evolution: Argon abundance and the discrimination between primordial and radiogenic Argon. Noble gas abundances; major element isotopes most importantly D/H, $^{14}\text{N}/^{15}\text{N}$, and $^{36}\text{Ar}/^{38}\text{Ar}$. The vertical distribution of CO and surface composition will also be measured.
- Chemical evolution: Abundance and identification of organic compounds and their variations with altitude. The surface composition, whether landing occurs in a hydrocarbon lake, aerosol bed, or icy terrain.
- Data Rate: 1700 bps

GCMS Parameters

- Mass: 17.3 kg
- Energy required for operation: 110 W
- Average power: 41 W
- Data rate: 1700 bps

Principal Investigator

Hasso B. Niemann
NASA Goddard Space Flight Center
Hasso.B.Niemann@nasa.gov

Co-Investigators

Sushil Atreya
University of Michigan

Siegfried Bauer
University of Graz

Klaus Biemann
Massachusetts Institute of Technology

George Carignan
University of Michigan

Thomas Donahue
University of Michigan

Daniel Gautier
Observatoire de Paris-Meudon

Don Hunten
University of Arizona

Guy Israel
Service d'Aeronomie du CNRS

Jonathan Lunine
University of Arizona

Konrad Mauersberger
Max Planck Institute

Tobias Owen
University of Hawaii

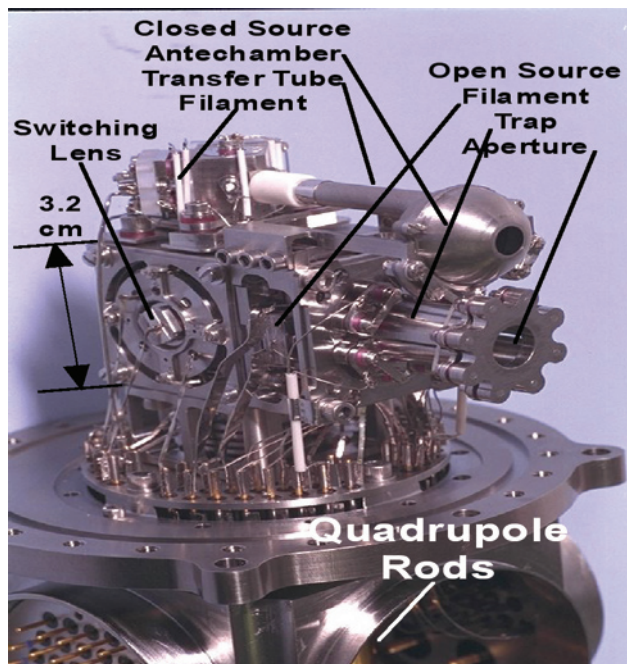
Francois Raulin
University of Paris Val de Marne

References

Niemann, H.B., et .al., 2002: The gas chromatograph mass spectrometer for the Huygens Probe. *Space Sci. Rev.*, **104**, 553–591.

INMS

Ion and Neutral Mass Spectrometer



Dual inlet gas/ion source

Key INMS Facts

- The INMS sensor is a quadrupole mass spectrometer designed to measure *in situ* low-density gas and positive ions in planetary upper atmospheres without pressure reduction.
- INMS is mounted on the fields and particles platform of the Cassini Orbiter. It will make measurements in Titan's upper atmosphere above 950 km, in the icy satellite environment and the inner magnetosphere of Saturn.
- Heritage: Upper atmosphere measurement missions: Atmosphere Explorer, Dynamics Explorer and Pioneer Venus. Dual ion-source/gas-inlet design: Comet Rendezvous and Flyby mission and CONTOUR (Comet Nucleus Tour) missions.
- Nominal Orbit Characteristics: Saturn Orbiter with flybys of Titan, its rings and several icy satellites.
- INMS URLs:
 - <http://sprg.ssl.berkeley.edu/inms/>
 - <http://saturn.jpl.nasa.gov/spacecraft/instruments-cassini-inms.cfm>
 - <http://hpcc.engin.umich.edu/CASSINI/INMS.html>

Description:

Cassini-Huygens is a mission to the Saturn system. It is a joint mission between the NASA Jet Propulsion Lab (JPL), which built the Orbiter, and the European Space Agency (ESA), which built the Huygens Probe. The spacecraft was launched on October 15, 1997; the Jupiter flyby was on

December 30, 2000, and Saturn orbit insertion was on July 1, 2004. The Huygens Probe entered Titan's atmosphere on January 14, 2005.

The Cassini orbiter is a three-axis stabilized spacecraft with 12 science instruments. Remote-sensing instruments include cameras, spectrometers, and radar and radio sensors. The fields and particles instruments take *in situ* direct sensing measurements of the environment around the spacecraft measuring magnetic fields, neutral and charged particle composition, the composition of dust particles and the properties of plasma waves. Three radioisotope thermoelectric generators provide spacecraft power.

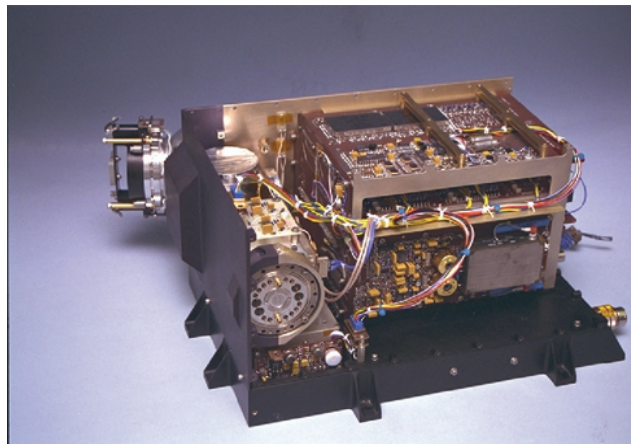
Cassini Orbiter science targets include Saturn and its rings, Titan (Saturn's largest moon with a substantial atmosphere of N₂, CH₄, and other hydrocarbons and nitriles), the icy satellites, and the Saturnian magnetosphere. INMS measurements are possible in all of these regions.

During the 4-year tour, the Orbiter will make 75 orbits around Saturn and 45 flybys of Titan, changing from near-equatorial to near-polar inclination.

INMS science objectives are to investigate:

1. The upper atmosphere of Titan, its ionization and its role as a source of neutral and ionized material for the Saturn magnetosphere
2. The environment of the rings
3. The interaction of the icy satellites and ring systems with the magnetosphere and possible gas injection into the magnetosphere
4. The effect of Titan's interaction with the solar wind and magnetosphere plasma
5. The interaction of Titan's atmosphere and exosphere with the surrounding plasma.

INMS was designed, constructed, tested, and calibrated by NASA GSFC, Code 699 (formerly Code 915). A Facility Science Team is performing operation and data analysis after spacecraft launch.



INMS electronics and sensor package.

INMS Data Products

- Titan upper atmosphere: neutral gas composition (H, H₂, N, NH, N₂, CH₄, HCN, C₂H₂, C₂H₄, and C₂H₆)
- Ion composition (N₂⁺/H₂CN⁺, C₂H₅⁺, CH₅⁺, CH₃⁺, CH₄⁺, C_mH_n⁺ (m = 4,5))
- Icy satellite and ring composition (H, OH, O; H⁺, H₂⁺, H₃⁺, O⁺, OH⁺, H₂O⁺, H₃O⁺, O₂⁺)

INMS Parameters

- Package mass: 10.29 kg (includes 1.4 kg tantalum radiation shield)
- Average power: 23.3 W, neutral mode; 20.9 W ion mode; 13.1 W sleep
- Package Size: 20.3 cm (H) × 42.2 cm (L) × 36.5 cm (W)
- Data rate: 1498 bps telemetry rate, 31.1 ms integration period, 34.0 ms total sample period
- Mass range: 1–8, 12–99 Da
- Electron impact ion source energy: 70 eV, 25 eV
- Detectors: Two secondary electron multipliers operating in pulse-counting mode
- Closed source: Spacecraft speed enhanced sampling of nonreactive neutral gases (e.g., N₂, factor 50); neutral source density >5 × 10⁴ cm³
- Open source: Sampling of neutral gas, neutral radicals and ions with no surface interaction (e.g., N, H₂CN⁺); neutral source density >2 × 10⁵ cm³; ion flux >10⁴ cm⁻² s⁻¹

Task Manager

Hasso B. Niemann
 NASA Goddard Space Flight Center
 Hasso.B.Niemann@nasa.gov

Facility Team Leader

J. Hunter Waite, Jr.
 University of Michigan

INMS Team Members

Thomas E. Cravens
 University of Kansas

Wing-Huen Ip
 National Central University

Wayne T. Kasprzak
 NASA Goddard Space Flight Center

Janet G. Luhmann
 University of California, Berkeley

Ralph L. McNutt
 Johns Hopkins University

Roger V. Yelle
 University of Arizona

JPL Investigation Scientist

Vincent G. Anicich
 NASA Jet Propulsion Laboratory

References

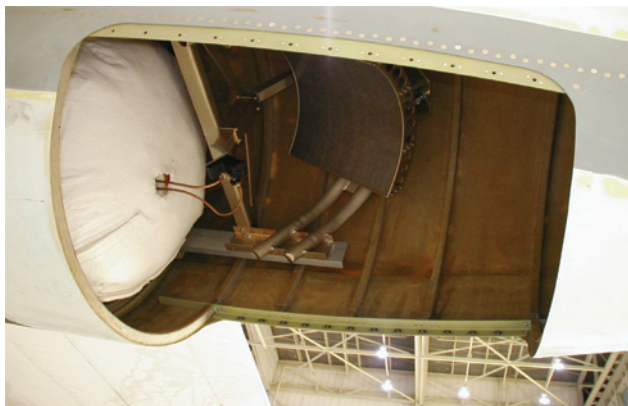
Waite, Jr., J.H., W.S. Lewis, W.T. Kasprzak, V.G. Anicich, B.P. Block, T.E. Cravens, G.G. Fletcher, W.-H. Ip, J.G. Luhmann, R.L. McNutt, H.B. Niemann, R.L. Thorpe, and R.V. Yelle, 2004: The Cassini Ion and Neutral Mass Spectrometer (INMS) investigation. *Space Sci. Rev.*, **114**(1–4), 113–231(119).

MICROWAVE INSTRUMENT SYSTEMS



CRS

Cloud Radar System



CRS instrument and antenna located in the tail section of an ER-2 SuperPod. The antenna points at nadir.

Key CRS Facts

- Heritage: Second generation ER-2 instrument based on the ER-2 Doppler Radar (EDOP). Several other ground-based and lower-altitude airborne W-band radars are present in the community.
- A Doppler weather radar system at W-band (94 GHz) developed for the ER-2 aircraft. Vertical profiles of radar reflectivity and hydrometeor motions are produced.
- The first deployment of CRS was in CRYSTAL-FACE during Summer 2002.
- Nominal aircraft configuration: The CRS system is configured for operation in the unpressurized tail-cone of an ER-2 wing SuperPod. The single nadir antenna radiates through a 20 in \times 20 in opening in the SuperPod.
- CRS URL: <http://rsd.gsfc.nasa.gov/912/radar/>

Description

Cloud radars at millimeter wavelengths have demonstrated high sensitivity to clouds. These radars, at frequencies above 35 GHz, have been used in various ground-based and airborne studies that focus on the effect of clouds on the Earth's radiation budget. The upcoming CloudSat mission has 94 GHz cloud radar as its primary instrument. Cloud radars have strong synergism with profiling backscatter lidars which have higher sensitivity to cirrus and other clouds, but whose signal becomes considerably more attenuated in thicker, more opaque clouds. The ER-2 platform provides the best satellite-like view of the tropospheric clouds and along with CRS, has a powerful suite of cloud remote sensing instruments. CRS is a W-band (94 GHz) cloud radar that is a fully coherent Doppler system with a fixed nadir pointing beam, which maps out Doppler winds and reflectivities in the vertical plane. CRS, combined with the existing CPL backscatter lidar system on the ER-2, provides a testbed for algorithms and a validation platform for the upcoming CloudSat and Calipso missions.

CRS Data Products

- Vertical profiles: radar reflectivity, hydrometeor and air vertical motions, ice and liquid water content, cloud layer locations
- Measurement interval: – 37.5 m vertical, 100 m along-track
- Measurement accuracy: reflectivity of 1.0 dBZ; winds at 0.5 ms⁻¹

CRS Parameters

- Transmitter peak power: 1.7 kW
- Frequency: 94.155 GHz
- Pulse repetition frequency: 4000/5000 Hz (staggered)
- Pulse width: 0.5 μ s.
- Receiver IF: 60 MHz
- Dynamic range: 80 dB
- Minimum detection signal: –29 dBZ (at 10 km range)

Principal Investigator

Gerald M. Heymsfield
NASA Goddard Space Flight Center
Gerald.M.Heymsfield@nasa.gov

CRS Team Members

Larry Belcher
Science Systems and Applications, Inc.

Lihua Li
Goddard Earth Sciences and Technology Center

Paul E. Racette
NASA Goddard Space Flight Center

Lin Tian
Goddard Earth Sciences and Technology Center

Edward Zenker
Science Systems and Applications, Inc.

Science Questions for Future Campaigns

1. What are the particle sizes and ice contents in thunderstorm-generated cirrus?
2. What is relation between convective intensity and the extent and depth of cirrus anvils generated by the convection?
3. What are the growth mechanisms in cirrus clouds?
4. What is the best approach for obtaining information on the cirrus properties using radar, lidar, and microwave and visible near-infrared radiometers?

Upcoming Field Campaigns

Tropical Cloud System Program (TCSP), Summer 2005

References

- Heymsfield, G.M., L. Li, L. Tian, M. McGill, and Z. Wang, 2003: Thunderstorm generated cirrus observed from X and W-band airborne radar during CRYSTAL-FACE. *Preprints, 31st AMS Conf. Radar Meteor.*, Seattle, Washington, 6–12 August, 2003.
- Li, L., G.M. Heymsfield, P.E. Racette, and L. Tian, 2003: Calibration of a 94 GHZ airborne cloud radar using measurements from the ocean surface. *Preprints, 31st AMS Conf. Radar Meteor.*, Seattle, Washington, 6–12 August, 2003.
- , G.M. Heymsfield, P.E. Racette, L. Tian, and E. Zenker, 2004: A 94 GHz cloud radar system on a NASA ER-2 aircraft. *J. Atmos. Ocean. Tech.*, **21**, 1378–1388.
- Tian, L., G. M. Heymsfield and L. Li, 2003: Stratiform precipitation observed by airborne radar at 94 and 10 GHZ. *Preprints, 31st AMS Conf. Radar Meteor.*, Seattle, Washington, 6–12 August, 2003.

EDOP

ER-2 Doppler Radar



Aft view of EDOP nose showing transmitter and data system.

Key EDOP Facts

- Heritage: Goddard/Communications Research Lab (Japan) dual-frequency airborne radar (Tropical Rainfall Measuring Mission [TRMM] algorithm development), lower altitude scanning Doppler radars.
- A Doppler weather radar system at X-band (9.6 GHz) was developed for the ER-2 aircraft. Vertical profiles of radar reflectivity and hydrometeor motions are produced.
- Participated in CAMEX 1, 2, 3, and 4; the Houston Precipitation Experiment (HOPEX); Texas and Florida Underflight Experiment (TEFLUN)-A and B, TRMM LBA, and CRYSTAL-FACE.
- Nominal aircraft configuration: The EDOP system is configured for operation in a refurbished military radar nose for the ER-2. Two fixed beams are used: one is pointing at nadir and the other is 33° forward of nadir.
- EDOP URL: <http://rsd.gsfc.nasa.gov/912/radar/>

Description

Airborne weather radar systems have played an important role in studying mesoscale convective systems (MCSs) and other mesoscale and cloud-scale phenomenon. These radars have provided important information on kinematic and dynamical aspects of isolated thunderstorms, MCSs, and hurricanes. Mesoscale phenomena often have long lifetimes (12–24 h), have large spatial extent (several hundred kilometers), and advect considerable distances over their lifetime. As a result, ground-based radars may not be suitably located for high-resolution measurements of MCSs and hurricanes because of either large radar slant ranges, or from the radars, or that the MCSs are located over open ocean. In addition,

most airborne weather radars are side-looking and do not provide coverage of the top portions of weather systems.

The system operates at X-band (9.6 GHz) and is a fully developed, coherent Doppler weather radar with fixed nadir and forward pointing beams that map out Doppler winds and reflectivities in the vertical plane along the aircraft motion vector. Doppler winds from the two beams can be used to derive vertical and along-track air motions. In addition, the forward beam provides linear depolarization measurements, which are useful in discriminating microphysical characteristics of the precipitation.

EDOP Data Products

- Vertical profiles: Radar reflectivity, hydrometeor vertical motions, u , w wind components, rain rate, hail, and melting layer discrimination.
- Measurement interval: 37.5 m vertical, 100 m along-track
- Measurement accuracy: Reflectivity at 0.5 dBZ; winds 0.5 m s⁻¹

EDOP Parameters

- Transmitter peak power: 22 kW
- Split between 2 antennas
- RF: 9.6 GHz
- Pulse repetition frequency: 4400 Hz
- Pulse width: 0.5 μ s
- Receiver IF: 60 MHz
- Dynamic range: >90 dB

Principal Investigator

Gerald M. Heymsfield
 NASA Goddard Space Flight Center
Gerald.M.Heymsfield@nasa.gov

EDOP Team Members

Larry Belcher
 Science Systems and Applications, Inc.

Steven Bidwell
 NASA Goddard Space Flight Center

Lihua Li
 Goddard Earth Sciences and Technology Center

Paul E. Racette
 NASA Goddard Space Flight Center

Rafael Rincon
 NASA Goddard Space Flight Center

Lin Tian
 Goddard Earth Sciences and Technology Center

Edward Zenker
 Science Systems and Applications, Inc.

Science Questions for Future Campaigns

1. What is the role of convective bursts on hurricane intensification and track?
2. What is the relation between convective intensity and the extent and depth of cirrus anvils generated by the convection?
3. What is the distribution of rainfall in landfalling hurricanes?
4. How well are hydrometeor particle size distributions represented in TRMM algorithms?
5. How does overshooting convection interact with the lower stratosphere?

Future Campaigns

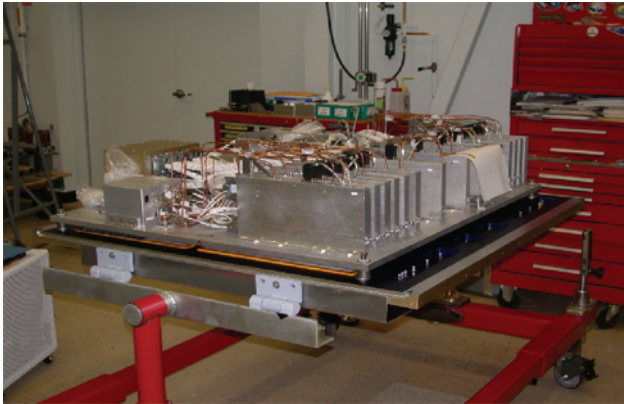
TCSP, Summer 2005

References

- Geerts, B., G.M. Heymsfield, L. Tian, J.B. Halverson, A. Guillory, and M.I. Mejia, 2000: Hurricane Georges' landfall in the Dominican Republic: Detailed airborne doppler radar imagery. *Bull. Amer. Meteor. Soc.*, **81**, 999–1018.
- Heymsfield, G.M., S. Bidwell, I.J. Caylor, S. Ameen, S. Nicholson, W. Boncyk, L. Miller, D. Vandemark, P.E. Racette, and L.R. Dod, 1996: The EDOP radar system on the high altitude NASA ER-2 aircraft. *J. Atmos. Ocean. Tech.*, **13**, 795–809.
- , J. B. Halverson, J. Simpson, L. Tian, and P. Bui, 2001: ER-2 Doppler Radar (EDOP) investigations of the eye-wall of Hurricane Bonnie during CAMEX-3. *J. Atmos. Meteor.*, **40**, 1310–1330.
- Tian, L., G. Heymsfield, and R.C. Srivastava, 2001: Measurement of attenuation with airborne and ground-based radar in convective storms over land and its microphysical implications. *J. Atmos. Ocean. Tech.*, **41**, 716–733.

LRR-X

Lightweight Rainfall Radiometer X-Band



LRR-X electronics base plate with subsystems installed.

Key LRR-X Facts

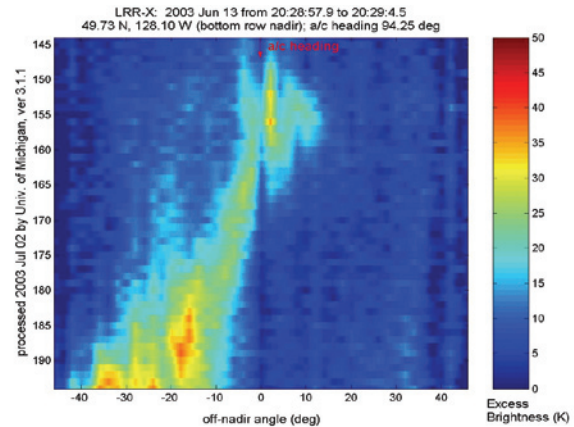
- Heritage: The Lightweight Rainfall Radiometer (LRR) was funded by the Earth Science Technology Office (ESTO) through the Instrument Incubator Program (IIP) program to develop a prototype synthetic thinned array radiometer (STAR) for measuring precipitation in the centimeter-to-millimeter spectrum. The instrument is an aircraft prototype of a synthetic thinned aperture radiometer (STAR) at 10.7 GHz for measuring over-ocean precipitation configured to fly on the NASA DC-8.

Description

Rainfall, along with temperature, are undoubtedly the variables, which will most directly affect mankind in an era of changing climate. The transient nature of rainfall, however, makes the detection of subtle changes difficult. With the successful launch and early operation of the joint US/Japan TRMM mission, the first systematic maps of global rainfall and the distribution of latent heating were produced in the tropics.

Looking toward the future, the LRR-X is a proof-of-concept (POC), aircraft demonstration instrument that is light enough, small enough, and economical enough to demonstrate the feasibility, as well as the validity, of a future STAR radiometer instrument system for small spacecraft. The design is a reduced risk approach for rainfall measurements. STAR technology provides wide swath push broom imaging with no moving parts, which significantly reduces spacecraft accommodation requirements. Additional technology developments associated with this project could lower

the cost and power and increase the reliability of spaceborne STAR sensors using: (1) a Monolithic Microwave Integrated Circuit (MMIC) for the analog receiver components; (2) an Application Specific Integrated Circuit (ASIC) low-power analog-to-digital converter for the MMIC receivers that has been optimized for use by a STAR sensor; and (3) an ultra-low power, high speed ASIC for the digital signal processing correlator stage of the sensor.



This image shows rain over the Pacific. This is the first LRR measurement from the NASA DC-8 showing the 10.7 GHz excess brightness temperature.

Principal Investigator

Eric A. Smith
NASA Goddard Space Flight Center
Eric.A.Smith@nasa.gov

LRR-X Parameters

- Horizontal polarization: 10.7 GHz
- Synthetic aperture: 1 m²
- Cross-track imaging
- Spatial resolution at 11 km altitude
- 381 m × 466 m (nadir)
- 4.36 m × 4.84 m (17° cross track)
- 1079 m × 629 m (45° cross track)

LRR-X Team Members

Christian Kummerow
Colorado State University

Caleb Principe
NASA Goddard Space Flight Center

Christopher Ruff
University of Michigan

RESEARCH AND DEVELOPMENT INSTRUMENT SYSTEMS



AirGLOW

A Direct Detection Doppler Wind Lidar for the Proteus Aircraft

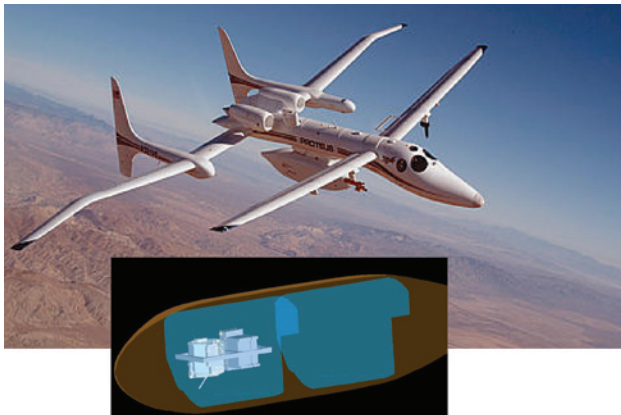


Fig. 1. Scaled composite's high altitude Proteus aircraft. The inset at the bottom is a conceptual model of the AirGLOW instrument inside the double Q-bay.

Principal Investigators:

Geary K. Schwemmer
Geary.K.Schwemmer@nasa.gov

Bruce M. Gentry
Bruce.M.Gentry@nasa.gov

Description

An enhanced knowledge of the global tropospheric wind field is widely recognized as fundamental to advancing the understanding and prediction of weather and climate. In addition, accurate global wind measurements are critical for safe and efficient military operations. A Doppler wind lidar (DWL) has the potential to provide wind observations from a space-based platform. A cost-benefit study has estimated that an operational wind lidar would result in a benefits-to-cost ratio of 3-to-1 from improved weather forecasts. A team of investigators from Goddard, Sigma Space Corporation, and Space Dynamics Lab have developed a conceptual design for an instrument we call AirGLOW, to demonstrate direct detection Doppler lidar measurements from either of two high altitude airborne platforms, the NASA ER-2 and Scaled Composite's Proteus aircraft. Both aircraft can cruise at, or near, 20 km altitude—a vantage point that enables a complete profile of the troposphere and helps to simulate space borne measurements with aircraft instruments. Both aircraft have a common instrument interface defined by mechanical and electrical specifications.

This interface was first developed for a fuselage instrument bay inside the NASA ER-2 called the Q-bay. A double Q-bay instrument accommodation has been implemented in a pod that hangs from the fuselage of the Proteus.

AirGLOW will serve as an important precursor demonstration prior to engineering a space borne wind lidar. We will borrow heavily from techniques and technologies we have

successfully implemented in existing lidar instruments: HARLIE, the Goddard Lidar Observatory-Winds (GLOW) and CPL. The approach will also use existing hardware or designs for major subsystems from existing development programs. As an example, several single-frequency lasers developed in recent NASA Small Business Innovation Research (SBIR) programs are being considered for use as the 355 nm wavelength laser transmitter.

Considerable savings in engineering time and development costs will be realized by modifying the mechanical design for the HARLIE scanner (Fig. 2) and incorporating a 355 nm Holographic Optical Element (HOE) also developed in SBIR-funded research, for the scanning telescope primary optic. A scaled-down version of the molecular double-edge receiver developed in the Zephyr program and successfully demonstrated in the GLOW ground based lidar (Fig. 3) is being developed for the Doppler receiver in the GSFC Independent Research and Development (IRAD) program. We will use techniques for dealing with the low pressure and temperature encountered at 20 km from the CPL (Fig. 4). The data system is also being developed under the SBIR program.

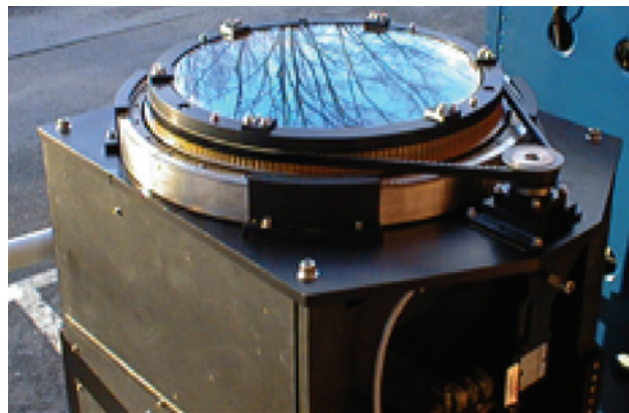


Fig. 2. The HARLIE scanning telescope is based on a rotating HOE that generates a conical scan pattern.



Fig. 3. The GLOW Doppler Wind Lidar.



Fig. 4. The Goddard CPL mounted in a pod that attaches to the wing of the NASA ER-2 aircraft.

Simulations show that line-of-sight velocity accuracy projected to the horizontal is $<1.5 \text{ m s}^{-1}$ for all altitudes using a 0.25 km vertical resolution and a 10 s integration throughout the troposphere in day and night.

AirGLOW is a candidate for being proposed to either the NASA IIP or the Earth System Science Pathfinder (ESSP) program. The development of the conceptual design is supported not only by the Goddard IRAD and SBIR programs, but also by the NPOESS Integrated Program Office.

Brewer

The Brewer Spectrophotometer



Fig. 1. The Brewer on the roof of GSFC Building 33.

Principal Investigator

Ernest Hilsenrath

Ernest.Hilsenrath-1@nasa.gov

Description

In late 2000, the Code 916 TOMS group purchased an MK IV Brewer Spectrophotometer primarily for use in the validation of EP-TOMS ozone measurements, but also for research on new methods to retrieve ozone and SO_2 , and for the retrieval of aerosol properties in the ultraviolet range. The MK IV Brewer has the capability to measure the intensity of ultraviolet radiation from 286–363 nm with a resolution of approximately 0.5 nm. While the standard “off-the-shelf” Brewer is a very flexible instrument, it was not suitable for our studies so we have modified it for sky radiance measurements by removing unneeded filters from the optical path and replacing them with a set of high-quality polarization filters. We have also developed cutting-edge algorithms to measure the ultraviolet intensity and retrieve ozone and aerosols.

Software: New Routines

The instrument has been well characterized and calibrated in the Code 613.3 (formerly 916) calibration laboratory facility. (This Brewer is arguably the best-characterized Brewer instrument in the world.) We have written new software to create flexible routines for lab calibrations, internal neutral density filter tests, new direct sun and zenith sky routines at medium (327–343 nm) and high (349–363 nm) wavelengths, solar plane scanning routines for polarized radiance and almucantar measurements, hyperspectral-scan routines, azimuth tracking test routines, and Sun-scanning routines to determine the instruments field of view, as well as polarized Umkehr (ozone profile) routines.

The instrument has been measuring total column ozone and SO_2 since November 2000, and has provided us with a useful time series, which has been used to validate the EP-TOMS instrument (Fig. 2). It has also yielded information about the daily changes in column ozone which cannot be seen by TOMS because of the satellite passing over Goddard only once in a 24 h period (Fig. 3).

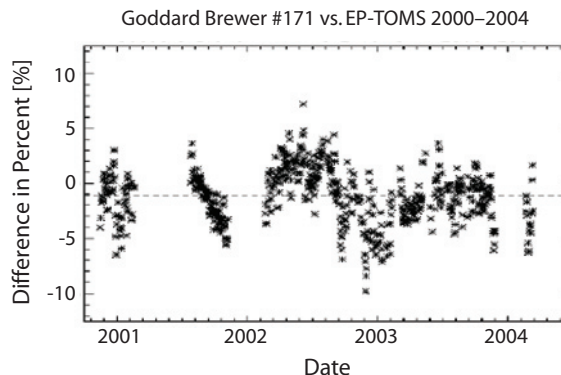


Fig. 2. Ozone from EP-TOMS compared with Brewer measurements (% difference).

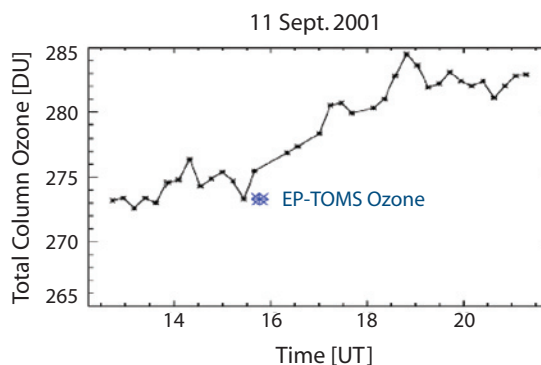


Fig. 3. Ozone change over one day measured by the Brewer.

Laboratory Calibrations

Extensive laboratory tests were performed and the following corrections were made to the instrument radiances:

- Correction for the hysteresis loss in the dynamic mode
- Dark count correction
- Neutral density filter attenuation correction
- Instrument temperature dependence correction
- Solar zenith angle correction

The following additional calibration tests have been performed:

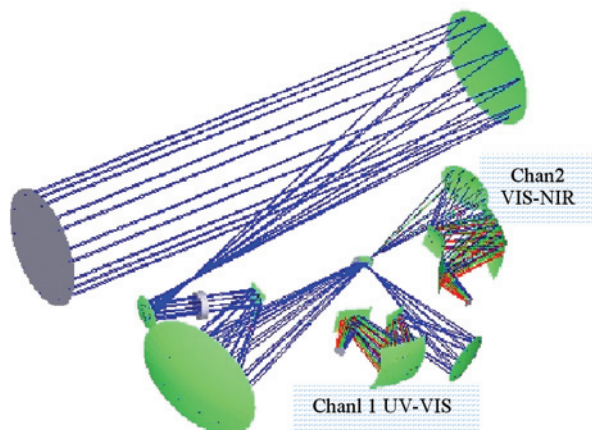
- A new wavelength-dispersion and slit function calibration using Hg- and Cd-lamps and a Dye-Laser.
- Brewer field of view and polarization sensitivity.
- Absolute radiometric calibrations for both radiance and irradiance mode.

Future Plans

- Polarization: We are in the process of building a curved quartz window to replace the factory unit (flat plate). This will reduce the polarization sensitivity of the Brewer to less than 2% and will enable us to do more aerosol studies.
- Calibration: We are comparing the laboratory calibrations to the standard Langley extrapolations. We will repeat the absolute calibration once the instrument is in its final configuration.
- Algorithms: We are developing new ozone, SO_2 , and aerosol algorithms by adding more wavelengths in the retrieval. We will reanalyze the data record using the newly developed algorithms and determine total ozone, total SO_2 , and aerosol optical depths. We will make polarized sky radiance measurements at GSFC (almucantar, solar plane, etc.). The data will be analyzed using existing algorithms (AERONET's almucantar-algorithm projected into the ultraviolet-range), as well as newly-developed algorithms.

GeoSpec

Geostationary Spectrograph for Earth and Atmospheric Science Applications



GeoSpec Layout: A 645 mm telescope coupled to a two-channel spectrograph; a technology prototype for demonstrating the feasibility of a space-flight instrument.

Principal Investigator

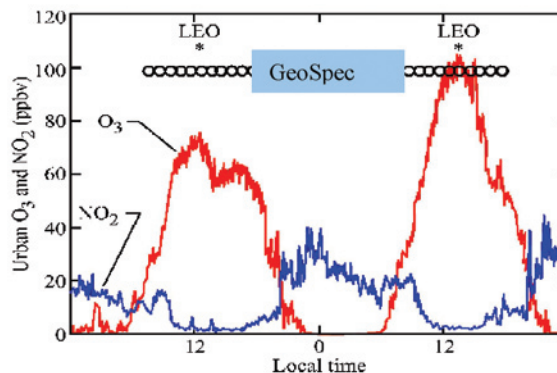
Scott J. Janz
Scott.Janz@nasa.gov

Description

GeoSpec Channel 1 measures from 300–480 nm to determine the amount of O_3 , SO_2 , and NO_2 in the Earth's atmosphere. Channel 2 covers the 480–940 nm spectral range for measurements important to ocean–land processes and coastal change. The technology demonstration is designed to show the feasibility of atmospheric trace gas retrievals using this type of spectrograph, in addition to testing new detector technology designed to increase the sensitivity in the ultraviolet range.

GeoSpec is designed to operate in a laboratory environment and then outdoors at both GSFC and at Washington State

University. The flight instrument that would be developed based on this demonstration is intended for a geostationary orbit to measure the variation in target gases throughout the day.



The GeoSpec instrument is designed to observe gases important for understanding atmospheric chemistry in the 300–480 nm range with a horizontal resolution of 5 km and the ability to scan continental size areas in 1 h. Resolutions down to 900 m will be achievable for regional studies of coastal ocean processes.

Advantages of a geostationary orbit: Diurnal variations in trace gas constituents can be resolved better than with typical Low-Earth Orbit satellites.

GeoSpec Parameters

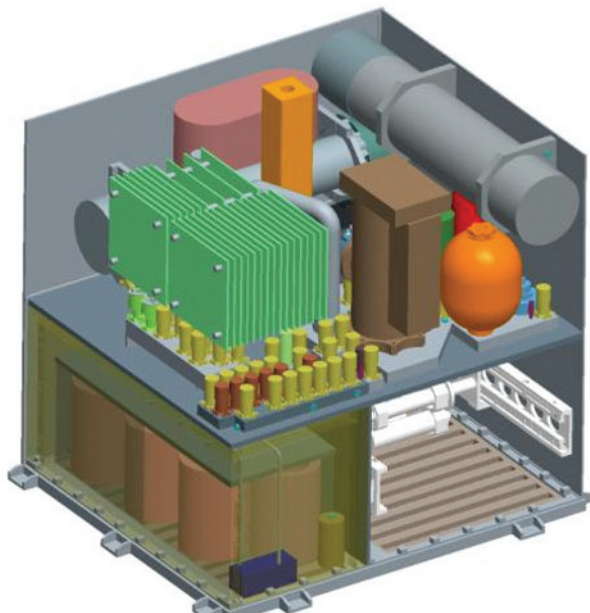
- Weight: 50 kg
- Length: 1 m
- Height: 0.4 m
- Power: 200 W

Special Features:

- High signal-to-noise ratio hybrid
- Complementary Metal Oxide Semiconductor (CMOS) array detectors
- High efficiency broadband depolarizer
- Diffraction limited optical resolution

In Situ

Technologies for Mars, Venus, and Comets



Principal Investigator

Dan N. Harpold
Dan.N.Harpold@nasa.gov

Advanced Organic and Isotope Analysis Protocols and Techniques

Development of advanced capabilities for *in situ* measurements of chemical and isotopic compositions in missions to Mars, Venus, and comets is supported by NASA technology development programs and with the participation of the Atmospheric Experiment Branch in the Goddard Node of the Astrobiology Institute.

Mars

The science driver for landed missions in 2009 and beyond is to ultimately answer the question, "Is there or was there ever life on Mars?" The systematic approach NASA has taken to answer this question is to explore the Mars system in greater detail from both the orbit and the surface, and then address the question of present or past habitability of this planet in even greater detail. One of the highly successful Mars Exploration Rover Missions discovered mineralogical and morphological evidence at the Mars surface of past aqueous conditions. Future investigations will not only "follow the water," but they will also carry out a search for reduced carbon species and make more comprehensive

mineralogical and isotopic measurements to address habitability.

Investigations of this scope have not been attempted since the ambitious Viking mission in 1976. The combination of new measurement technologies, the ability to deliver substantial payload mass to the surface of Mars, our greatly improved knowledge of the Martian system, and our understanding of the variety of microbial terrestrial life forms and their signatures ensures that future surface investigations will enable significant advances from past landed investigations.

Venus

Although several NASA and Russian spacecraft entered the atmosphere of Venus over the past four decades, key measurements of inert noble gases that trace the atmospheric evolution of this planet have not yet been made. Static mass spectrometer techniques are now being developed for space use, which can obtain these measurements with the precision required.



Comets

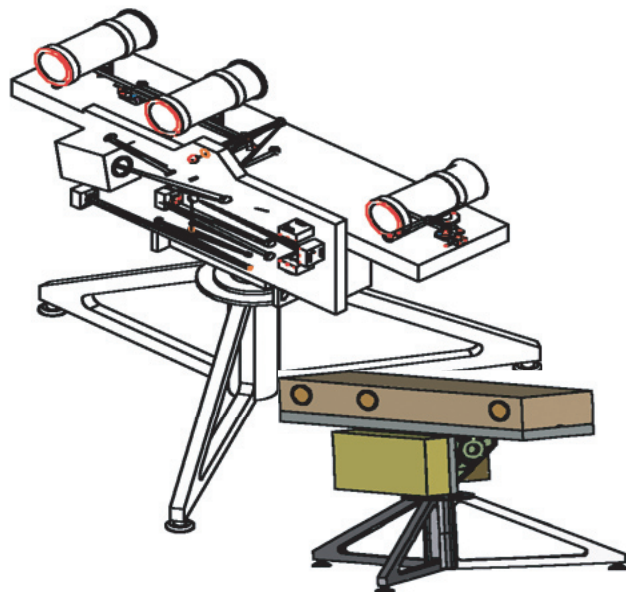
Exploration of comets with mass spectrometers that can measure their organic and isotopic composition can reveal chemical conditions preserved from early in the history of the solar system. Comets may have contributed volatiles to the terrestrial planets to form their atmospheres and the Earth's oceans; only exploration of the composition of comets will enable us to understand the nature and extent of this contribution. The measurement technologies described will be used in complementary missions as these opportunities arise.

New Mission Opportunities

NASA programs such as Discovery, New Frontier, and the Mars Exploration Program will provide the support for these investigations. Goddard will collaborate with universities and other laboratories to respond to these opportunities.

SVIP

Solar Viewing Interferometer Prototype



A 1.25 m, three-telescope, Fizeau interferometer and spectrometer technology prototype for demonstrating the feasibility of a space-flight instrument.

Principal Investigator

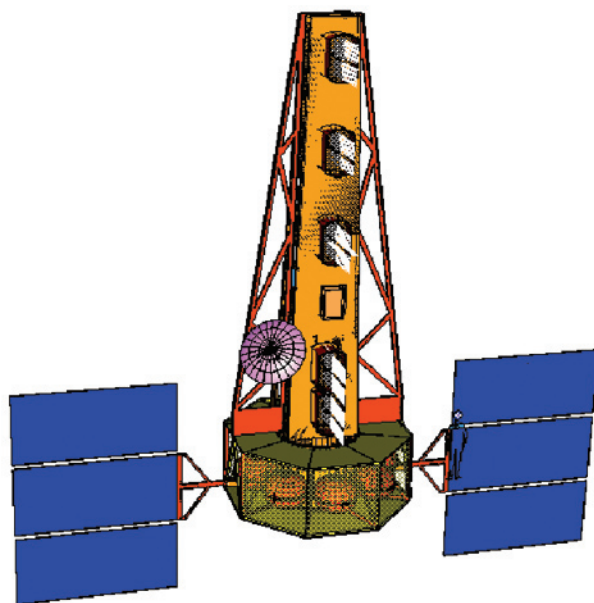
Jay R. Herman
Jay.R.Herman@nasa.gov

Description

SVIP makes measurements from 1–2 μ to determine the amount of CO₂, H₂O, and CH₄ in the Earth's atmosphere. The technology demonstration is to show the feasibility of closed-loop control active optics to compensate for air turbulence and the natural instrument vibrations. Optical corrections are made 800 times per second.

SVIP is designed to operate in a laboratory environment and then outdoors at GSFC and on a mountaintop. The flight instrument Earth Atmosphere Solar Interferometer (EASI) is intended for an orbit at L-2 looking at the Sun through the Earth's atmosphere.

The EASI interferometer–spectrometer is designed to observe the Earth's greenhouse gases in the 1–5 μ range with a spatial resolution of 1 km altitude, 0.1° latitude, and 2° longitude. The goal is to obtain the first 3-D measure of the entire Earth's atmosphere once per day.



Possible design of the 8 m, five-telescope, L2-EASI interferometer–spectrometer instrument and spacecraft.

Orbit Configuration Summary

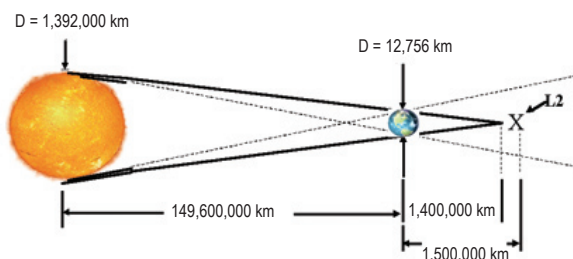


Figure courtesy of EASI

SVIP Parameters

- Weight: 70 kg
- Length: 1.25 m
- Height: 1 m
- Power: 200 W

Special Features:

- Optical stability of 0.1 μ
- 15 onboard Digital Signal Processing (DSP) computers
- 5 CCD cameras
- 1 spectrometer

UAV CPL

Unmanned Aerial Vehicle Cloud Physics Lidar



Fig. 1. The Global Hawk aircraft.

Principal Investigator

Matthew J. McGill

Matthew.J.McGill@nasa.gov

Description

Based on the success of the ER-2 Cloud Physics Lidar, or CPL (see <http://cpl.gsfc.nasa.gov>), a similar instrument is under construction for use on Unmanned Aerial Vehicles (UAVs). The specific target aircraft is the Global Hawk (Fig. 1), as it is widely presumed that NASA will obtain license to at least one, if not two, Global Hawks in the near future.

Global Hawk is a large aircraft, and the CPL instrument package fits nicely into the nose section. Figure 2 shows a graphical representation of the lidar installation in the Global Hawk.

Data products and data quality will be similar to the current ER-2 CPL instrument. Using the proven ER-2 instrument as a design base permits easy and inexpensive construction of the Global Hawk lidar. The long duration flights possible with the Global Hawk should prove useful in future science

campaigns, allowing, for example, study of cyclogenesis life cycle from formation up through dissipation.

The lidar instrument is a backscatter lidar designed to operate simultaneously at three wavelengths: 1064, 532, and 355 nm. The lidar uses state-of-the-art technology with a high repetition rate, low-pulse energy laser, and photon-counting detection. Vertical resolution of the measurements is fixed at 30 m; horizontal resolution can vary, but is typically 1 s. Its primary instrument parameters are listed below.

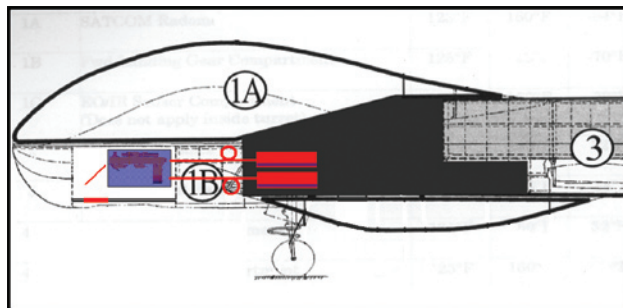


Fig. 2. The CPL instrument package is mounted in the Global Hawk nose section. The blue box (left) is the lidar instrument and the red boxes (center) are the data system and laser power supply.

UAV Parameters

- Laser wavelengths: 1064, 532, 355 nm
- Laser type: solid state Nd:YVO₄
- Laser repetition rate: 5 kHz
- Laser output energy: 50 μ J at 1064 nm, 25 μ J at 532 nm, 50 μ J at 355 nm
- Telescope: 20 cm diameter, off-axis parabola
- Telescope FOV: 100 μ rad, full angle
- Raw data resolution: 1/10 s (30 m \times 200 m horizontal)
- Processed data resolution: 1 s (30 m \times 200 m horizontal)
- Instrument weight: Approximately 200 lbs
- Duration: Up to 36 h
- Flight altitude: 50,000–60,000 ft

ACRONYMS



ACRONYMS

AASI	Antarctic AMSR-E Sea Ice Mission
ACP	Aerosol Collector Pyrolyzer
AERONET	Aerosol Robotic Network
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	AMSR Earth Observing System (EOS)
ARM	Atmospheric Radiation Measurement (Program)
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ASIC	Application Specific Integrated Circuit
AT Lidar	Aerosol and Temperature Lidar
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection And Moisture EXperiment
CCD	Charge Coupled Device
CloudSat	Cloud Satellite
CLS	Cloud Lidar System
CMOS	Complementary Metal Oxide Semiconductor
COMMIT	Chemical, Optical, and Microphysical Measurements of <i>In situ</i> Troposphere
CONTOUR	Comet Nucleus Tour
COVIR	Compact Visible and Infrared Radiometer
CPL	Cloud Physics Lidar
CRS	Cloud Radar System
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers— Florida Area Cirrus Experiment
DDF	Director's Discretionary Fund
DIAL	Differential Absorption Lidar
DOE	Department of Energy
DSCOVR	Deep Space Climate Observatory Project (formerly Triana)
DSP	Digital Signal Processing
DWL	Doppler Wind Lidar
EASI	Earth Atmosphere Solar Interferometer
EDOP	ER-2 Doppler Radar
EOS	Earth Observing System
EPIC	Earth Polychromatic Imaging Camera
EP	Earth Probe
EP-TOMS	Earth Probe TOMS
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
GCMS	Gas Chromatograph Mass Spectrometer
GeoSpec	Geostationary Spectrograph
GLOW	Goddard Lidar Observatory for Winds
GOME	Global Ozone Monitoring Experiment
GPM	Global Precipitation Measurement
HARGLO	Intercomparison of Wind Profile Systems experiment involving the HARLIE and GLOW instruments
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HOE	Holographic Optical Element
HOPEX	Houston Precipitation Experiment
IHOP	International H ₂ O Project
IIP	Instrument Incubator Program
INMS	Ion and Neutral Mass Spectrometer
IR	Infrared
IRAD	Independent Research and Development

ISIR	Infrared Spectral Imaging Radiometer
ITCZ	Intertropical Convergence Zone
KILT	Kiritimati Island Lidar Trailer
LRR-X	Lightweight Rainfall Radiometer X-Band
MCS	Mesoscale Convective System
MMIC	Monolithic Microwave Integrated Circuit
MPL	Micro-Pulse Lidar
MPLNET	Micro-Pulse Lidar Network
NASA	National Aeronautics and Space Administration
NDSC	Network for the Detection of Stratospheric Change
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar Orbiting Environmental Satellite System
NPP	NPOESS Preparatory Project
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapper and Profiler System
OSIRIS	Odin Spectrometer and IR Imager System
P	Pressure
PBL	Planetary Boundary Layer
POC	Proof-of-Concept
POES	Polar Orbiting Environmental Satellite
PPI	Plan Position Indicator
PRF	Pulse Repetition Frequency
PSC	Polar Stratospheric Clouds
RASL	Raman Airborne Spectroscopic Lidar
RCDF	Radiometric Calibration and Development Facility
RF	Radio Frequency
RGB	Red, Green, Blue
RH	Relative Humidity
RHI	Range-Height Indicator
SAGE	Stratospheric Aerosol and Gas Experiment
SBIR	Small Business Innovative Research
SBUV	Solar Backscatter Ultraviolet
SBUV-2	Solar Backscatter Ultraviolet/version 2
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SOLVE	SAGE III Ozone Loss and Validation Experiment
SRL	Scanning Raman Lidar
SSBUV	Shuttle Solar Backscatter Ultraviolet
STAR	Synthetic thinned Away Radiometer
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
SVIP	Solar Viewing Interferometer Prototype
T	Temperature
TCSP	Tropical Cloud System Program
TEFLUN	Texas and Florida Underflights Experiment
THOR	cloud THickness from Offbeam Returns
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmosphere Research Satellite
UAV	Unmanned Aerial Vehicle

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>						
1. REPORT DATE (DD-MM-YYYY) 31-07-2005		2. REPORT TYPE Technical Publication		3. DATES COVERED (From - To)		
4. TITLE AND SUBTITLE Laboratory for Atmospheres: Instrument Systems Report				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Laboratory for Atmospheres				5d. PROJECT NUMBER		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Goddard Space Flight Center Greenbelt, MD 20771				8. PERFORMING ORGANIZATION REPORT NUMBER 2005-01150-0		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITOR'S ACRONYM(S)		
				11. SPONSORING/MONITORING REPORT NUMBER TM-2005-212783		
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited, Subject Category: 47 Report available from the NASA Center for Aerospace Information, 7121 Standard Drive, Hanover, MD 21076. (301)621-0390						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT Studies of the atmospheres of our solar system's planets—including our own—require a comprehensive set of observations, relying on instruments on spacecraft, aircraft, balloons, and on the surface. Laboratory personnel define requirements, conceive concepts, and develop instrument systems for spaceflight missions, and for balloon, aircraft, and ground-based observations. Laboratory scientists also participate in the design of data processing algorithms, calibration techniques, and the data processing systems. The instrument sections of this report are organized by measurement technique, e.g., active, passive, and in situ. Active systems include lidar and microwave radar, passive systems include optical and microwave systems, and in situ systems consist of mass spectrometers for planetary atmosphere measurements. A number of instruments are in various stages of development or modification and are also described. This report will be updated as instrument systems evolve and change.						
15. SUBJECT TERMS Laboratory for Atmospheres, Atmospheric Research, Instrument Systems						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19b. NAME OF RESPONSIBLE PERSON	
a. REPORT	b. ABSTRACT	c. THIS PAGE			Charles Cote	
Unclassified	Unclassified	Unclassified	Unclassified	59	19b. TELEPHONE NUMBER (Include area code) (301) 614-6367	

